Tree root plate assessment by sounding

Frank Rinn

FAILURE OF URBAN TREES is often a consequence of root decay and injury. Sometimes symptoms of root problems are visible at the stem base, but for the most part, it is impossible to assess root condition, and determine the size of the mechanically active anchorage- (root-) plate from an above ground inspection. Root excavation is not always an option because of pavement, underground service lines, or just because of the labor and high costs involved.

From experience, we know that previous diagnostic methods did not always allow us to adequately assess root condition or stability. Measurement of inclination of trees while under artificial loading in a pull-test, or during storms can indicate anchorage problems, but tree-pulling is expensive because it requires highly sophisticated equipment and experienced experts, and is rather time-consuming. And, it does not show where structural roots are located or indicate how decay, resulting from root injury, will develop in the future.

Ground penetrating radar (GPR) can generally reveal the root system of trees in open land and in park situations, but often fails to identify roots in urban settings and along roads. It cannot reliably distinguish between roots and utility lines, such as gas and water pipes. Because roots often grow under and along such pipes, they are nearly invisible to GPR. In addition, for trees growing in close proximity, it can be difficult determining which tree a particular root detected using GPR is associated with. Lastly, applying GPR is expensive and time-consuming, and thus, most applicable in special cases, for example the preparation of the transplantation of big trees.

Consequently, after a few years of experience with sonic tomography (Rinn 1999), we looked for a method to determine the size of the mechanically-active root plate in 2003. In Germany, we often face the problem that trees may have serious root problems, yet appear reasonably healthy. For example, it's not uncommon for horse chestnut trees (*Aesculus hippocastanum*) to uproot due to missing or severely decayed structural roots, despite a normal appearance. In such cases, we often did not find any significant roots within one or two meters of the stem because they were severely decayed (Rinn 2004, 2005). When such trees uproot, there is often little or no lifting of soil and associated roots-plate when the stem topples or uproots. Normally, when a sound tree uproots, the root plate and the soil above it are lifted on the side where the roots failed. This led to the idea of measuring the mechanical connection between the roots and soil around the stem base. If soil is mechanically connected to the tree (by roots), it helps to anchor the roots, keeping the tree upright. Thus, the soil mechanically connected to the stem base would be (at least partially) uplifted when the tree uproots. So, we assumed that it should be possible to determine the size of the anchorage plate by measuring mechanical connection of the soil around the tree to the stem base.

> *…it should be possible to determine the size of the anchorage plate by measuring mechanical connection of the soil around the tree to the stem base.*

Because sonic tree tomography primarily determines the quality of mechanical connection between sending and receiving sensors by measuring time of flight of stress waves (Rinn 2014, 2015), we wanted to test if this principle could be applied to the root plate as well. As common for sonic tomography at the stem base, we placed one sensor on each of the major root buttresses. Then we took one additional sensor attached to a steel rod, placed it on the ground around the tree and tapped on it. The sensors at the tree then determined if the signal (=stress wave), induced by tapping, arrived at the stem base in the form of a vibration (stress wave). If the soil at the tapping point is mechanically connected to the tree (most likely by roots) a signal should be detected by at least one of the vibration sensors at the tree.

The measurement process is quick and easily done, however, there are many aspects, such as the influence of soil compaction, soil coverage, depth of soil, and moisture, etc., to be considered. After the success of early applications, this method (we call it "Arboradix") became known in the market. Soon, more and more experts wanted to use the method for accurately locating roots, not just

Figure 1. Chosen tree for root plate assessment on the DAVEY site of the ISA tree-biomechanics week 2013.

roughly determining the mechanical connectivity of the roots (root plate) and soil. This, however, was not what we had originally set out to do, but because it would be an interesting extension of the technology, we took additional steps to investigate this potentially useful application.

For a better understanding of the possibilities and limitations of this method, we applied it on trees as part of the ISA biomechanics week in 2013 in Ohio. A reasonably sized maple tree was selected (**Fig. 1**) where we would be allowed to excavate the roots afterward after testing to cross-check results. Sebastian Koerber (Miami, Fl) assisted in the sonic root tests, several arborists helped afterward by excavating the roots (a very dirty job — thanks again!). In addition, Bodo and Tobias Siegert (Altdorf, Germany) carried out a GPR assessment with their double-antenna system at the same tree. The very interesting results of this comparison shall be described in a future article.

First, we established a 50 x 50 cm^2 (~20 in x 20 in) grid around the tree with lines and red dots marked on the ground (**Fig. 2**) to exactly locate the points of tapping. Then we placed sensors at the stem base, as we would do for a standard sonic tomography (**Fig. 3**). Afterwards, an additional sonic sensor, fixed to a steel rod, was electronically connected to the sensor-chain around the stem base. We then tapped on every grid point around the stem (**Fig. 4**). We always started at points closest to the stem and moved away from the tree while tapping in one direction until a signal was no longer detected at any of the receiving sensors. The common approach for a typical urban tree is much simpler, just moving outward from the tree in a star-like pattern in steps of typically 1m (~40 in) until no signal is detected.

Figure 2. (Left) Around the tree, a regular grid (50cm x 50cm ~ 20in x 20in) was marked using lines and red dots on the ground in order to exactly locate the points of tapping. The common approach at a tree is different. Usually, we start tapping in a distance of 1m (~3ft) from the tree and then go away from the tree in the same direction by tapping steps of 1m. This way, a star like pattern is built up.

Figure 3. (Right) Sonic (stress wave) sensors at the stem base for a standard sonic tomography (Rinn 1999).

Figure 4. Tapping on a steel rod induces a (compression) stress wave into the ground. A sonic (stress wave) sensor is attached to this rod, connected to the sensors at the stem base with a conventional computer cable (up to 20m ~60ft long). As soon the rod is tapped (with an ordinary hammer), the rod-sensor detects this as the starting time of the stress wave. Via cable this information is sent to the sensors at the tree stem base, in order to start their clock and to listen to waves coming in. As soon as a sensor at the stem base measures an incoming stress wave, this stops the corresponding clock and thus measures time of flight. Dividing the distance to the tapping point by this time of flight, delivers a virtual speed.

The software shows the grid points around the centrally located stem (**Fig. 5**) where the steel rod was placed and tapped using an ordinary hammer. When this mechanical signal (=stress wave) is detected by a sensor at the tree, the software draws a colored line from the receiving sensor to the corresponding tapping point. Sometimes only one sensor received

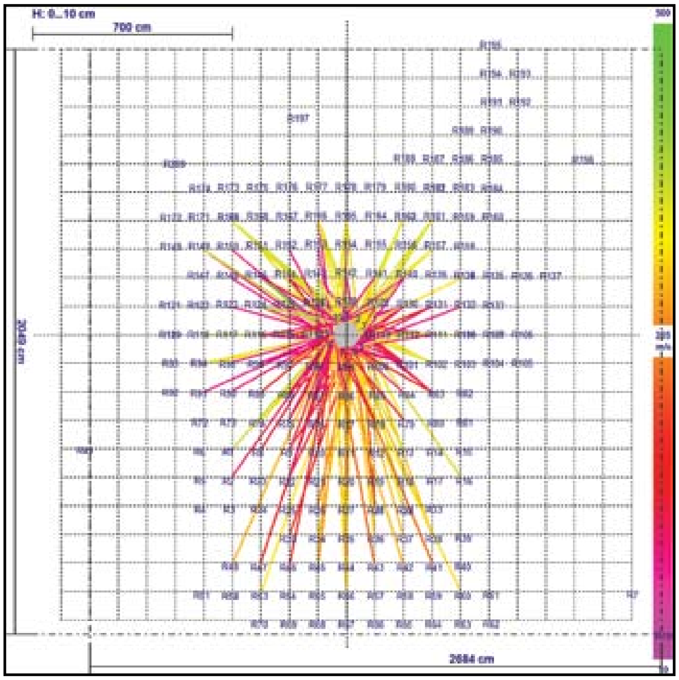

Figure 5. (Left) If a sensor at the stem base detects a signal, the software draws a line from this sensor to the tapping point. The color of each line indicates the overall (thus virtual) speed of the signal from the tapping point to the tree. These values typically vary between 0 and 500m/s. We commonly use green for high (virtual) speed, yellow for average, red to purple for low speeds. However, because of many influencing factors, we do not yet use the color of the lines for evaluation. Shallow and bigger roots, for example, mostly lead to higher sonic speeds. Higher moisture contents in the ground, leads to lower sonic speed. High compaction increases the virtual sonic speed. As long as there is no clear correlation established between virtual sonic speed, this value is not yet regarded fully.

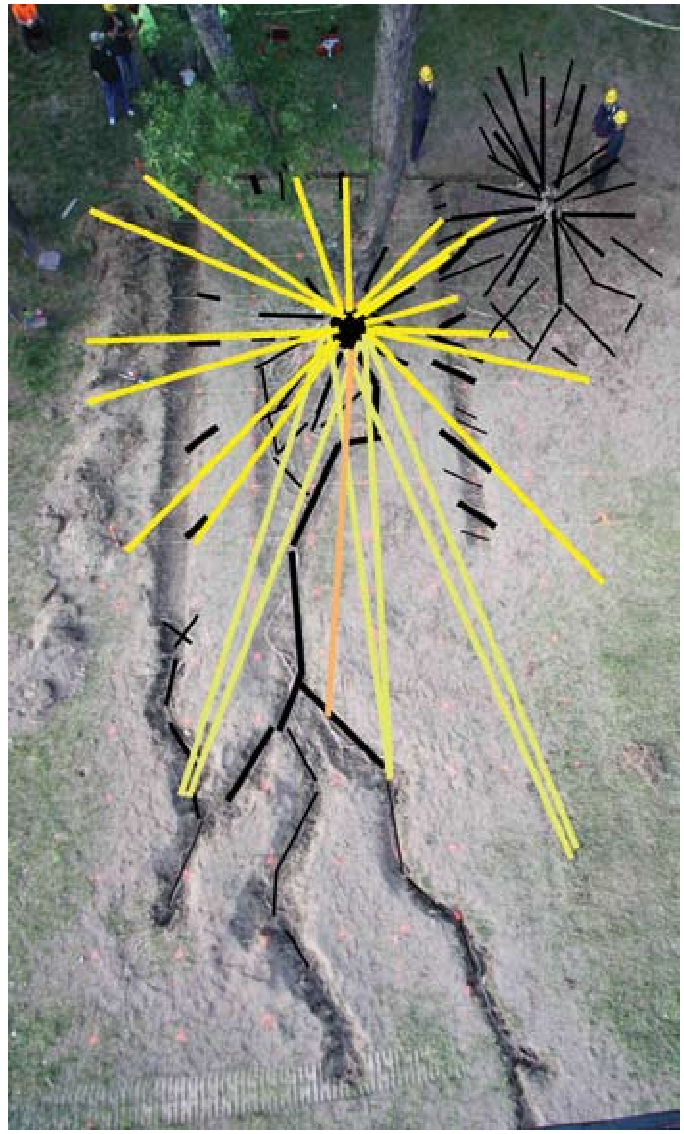

Figure 6. (Right) Superposition of an excerpt of the root-line-graph (Fig. 5) and an aria picture of the root plate after first steps of excavation. Even at the tapping points, the end of the yellow lines (indicating mechanical connection as measured by the sonic sensors) far away from the tree to the south at a distance of more than 20 feet, structural roots (black lines) were found in the soil.

such a signal, sometimes several, sometimes none.

The color of each line indicates the overall (thus virtual) speed of the signal from the tapping point to the tree. These values typically fall between 0 and 500m/s. We commonly use green for high (virtual) speed, yellow for average, red to purple for low speeds. After the measuring was done and the data saved, the excavation team exposed the structural (lateral) roots using a pneumatic excavation tool, and followed them outward from the tree.

The test which was done in several different modes and using various analysis and filtering procedures, produced a lot of data to work with. All this shall be described in a more scientific article in the future. Here, I want to focus on the main results: below every tapping point, from where a signal was detected at the tree, we found an intact root of at least 3cm (>1in) in diameter and not deeper than 30cm (~1ft) in the soil. Even at a distance of more than 10m (>30ft) from the tree, where we thought the system was giving false readings, we found structural roots at all tapping points that had created a signal line to at least one sensor at the tree base (**Fig. 6**). At all excavated tapping points, from where no signal was detected at the tree, we found only fine roots or no roots.

These results confirmed our findings from many practical analysis since 2004. If we did not detect any significant signals at tapping points within 1 or 2m of the stem, we concluded that most of the structural roots were missing (due to decay or root severance, e.g., trenching, excavation, or root pruning for sidewalk repair) and the tree was therefore considered high risk.

These results have raised some interesting questions with respect to roots that will need to be investigated. The next step of our scientific analysis is to correlate the virtual speeds of the signals (represented by different colors) to size, and/or depth of roots, soil moisture content, and level of soil compaction. The potential for this method to produce reliable information regarding root condition has not been fully determined. More testing will be needed.

Frank Rinn
Heidelberg, Germany

Literature cited:

Rinn, F. 1999, Device for investigating materials. International Patent PCT/DE00/01467 (Pr. 11. Mai 1999).

Rinn, F. 2005, Den Wurzeln auf der Spur. DeGa 2/2005, S. 14.

Rinn, F. 2008, Wurzeldiagnose mit Schalltomographie AFZ 12/2008.

Rinn, F. 2014. Central Basics of Sonic Tree Tomography. Journal of the Society of Commercial Arborists (SCA-Today), Dec 2014, Vol. 19, No. 4, pp. 8-10.

Rinn, F. 2015. Central defects in sonic tomography. Western Arborist. Spring 2015, 38-41.