Central defects in sonic tree tomography

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Abstract:
Starting in 1999, sonic tomography developed into a standard tool for advanced technical tree safety inspection, and is now applied by more than one thousand tree-experts worldwide. Several aspects of this method need to be explained in detail because they contradict the common assumption, for example how central decay or defects such as ring- shakes appear in the tomogram. Understanding the physical principles of the method are critical for a correct interpretation of such results, and that the tomogram cannot reveal the overall condition of the wood, only the interconnected parts of the cross-section contributing to the load carrying capacity.

Keywords:
sonic tomography, tree safety, ring-shake, resistance drilling, decay detection

Introduction

Sonic tomography was developed to provide an easy to comprehend representation of the whole cross section of tree stems subject to technical safety inspection (Rinn 1999). Although the results (tomogram pictures) commonly use a velocity scale to distinguish between the different colors, the method does not measure sonic speed (Rinn 2014). The sensors just detect the starting and arrival time of stress waves and determine the difference, often called

Because trees are usually tested technically when damage is present or suspected, the aspects described have to be understood before using and interpreting sonic tomography for tree-safety evaluations.

Figure 1. Cross section of a stem of *Castanea sativa*. At first glance and even after tapping, the wood sounded intact. The discolorations appeared days after the felling and were not visible on the fresh wood.

'time of flight'. When there is decay, resulting in ring separations (shakes) between the sending and receiving sensor for example, the measured (= fastest) stress waves travel on a detour around the defect and not straight through it. Consequently, in such cases, the given speed in sonic tomogram pictures is 'virtual' and, by physical principles, cannot correlate to the density or any other material properties of wood within the deteriorated part. This was clear from the beginning of the development of the method in the early 1990s and has many implications and (positive) consequences for tree-safety evaluations. Because trees are usually tested technically when damage is present or suspected, the aspects described here have to

Figure 2. A closer look on the surface after grinding shows that there is a decay that deteriorated the early-wood of a central ring, in a nearly concentric pattern. The wood outside and inside of this decay was intact.

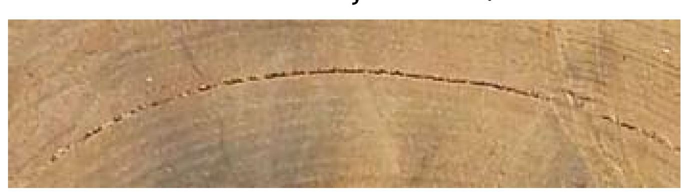


Figure 3.(Left) The red circles indicate the decayed tree-rings (ring-shake). In addition, some small areas showed remains of previous damages (marked red).

Figure 4. (Right) For scientific purposes, 15 stress wave sensors were placed around the stem for obtaining a sonic tomogram picture. In a 'real' world inspection, for such a cross section, typically 8 to 10 sensors would be used and sufficient.

be understood before using and interpreting sonic tomography for tree-safety evaluations. What this means is that this kind of sonic tomography cannot reveal the wood's condition throughout the cross-section when there are defects present.

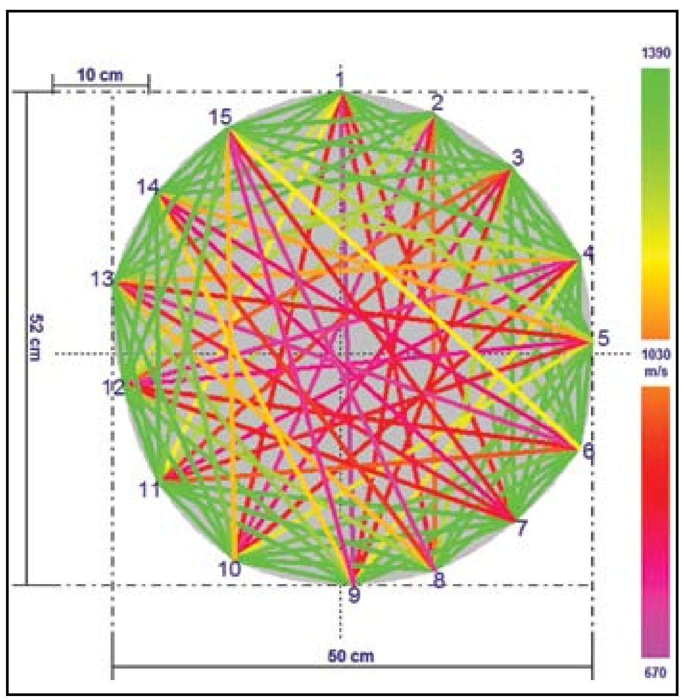
Ring-shake decay

Some tree species sometimes show a specific decay pattern where, in the early or incipient stage, the earlywood of only one or a few rings is decayed (**Figs. 1-2**). This causes a separation of two latewood zones by degrading the earlywood zone in between. The decay can start as a result of stem wounds or moves upward from the roots. In an examination of 12 stems of approximately 60 year-old *Castanea sativa* trees in Heidelberg, Germany, ring-shake decay was found in more than 50% of the trees, sometimes ranging from the trunk base several meters up the stem. In some cases, in addition, small wounds were identified from past stem damages (**Fig. 3**).

Sonic tomography

Stress-wave sensors were placed around the cross section (**Fig. 4**) at the same level for obtaining a colored sonic tomogram of one typical stem disk showing a ring-shake. The virtual speed of the stress-waves was visualized by different colors of the lines between the sensors: green for fast, yellow for average, red for slow, and purple for very slow (**Fig. 5**). The 'line-graph' indicates that the stress

Figure 5. (Below) The color of the lines from every sending to every receiving sensor visualizes the virtual speed: green means the stress wave traveled fast (and nearly straight). Yellow, red, and purple mean the waves had to take a more or less far detour (around damages). The more red and purple the line the longer the detour.



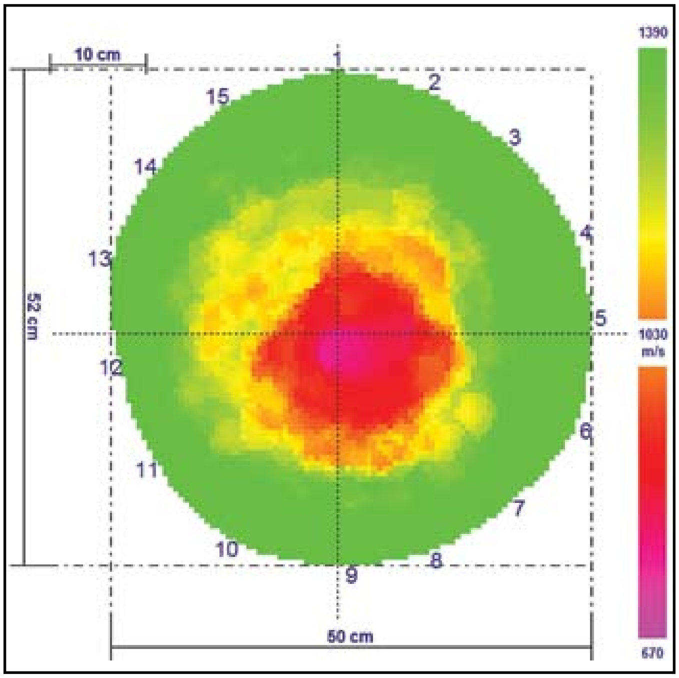


Figure 6. Based on the line graph, a special computer program automatically calculates a 2d-tomogram picture visualizing the internal situation: this does not and cannot, in general, reveal overall local wood condition but just shows the remaining (wind-) load carrying parts in green (these are the intact and mechanically interconnected parts of the cross section).

waves obviously were not able to penetrate through the center of the tree but had to take a detour. The more red or purple the color, the bigger or longer the detour.

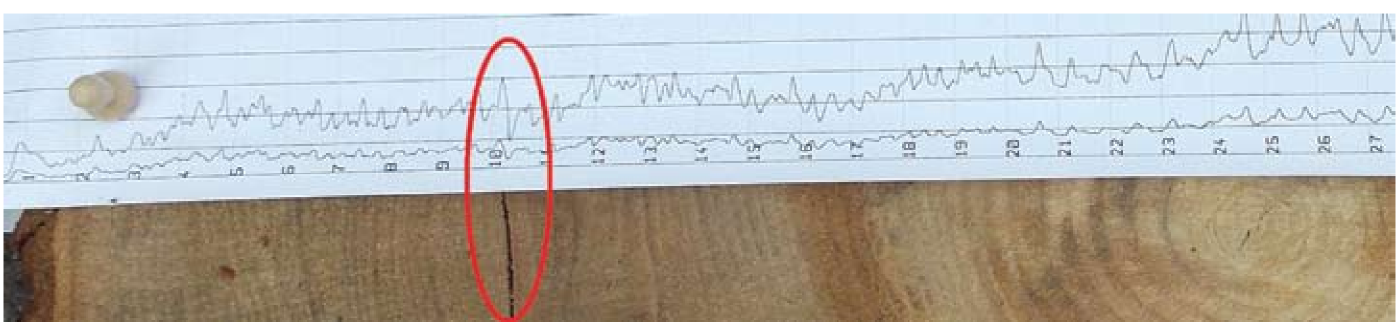
The resulting tomogram picture (**Fig. 6**) shows a red area in the center - although the center of the cross-section was intact as can be seen in the picture of the stem disk (**Figs. 1- 2**). This anomaly often 'surprises' practitioners, and even some experts, after they remove the tree and are unable to find extensive decay. It can also be upsetting to nonprofessionals because they think the machine was wrong. After cutting the stem disc with a chainsaw, ring-shake decay as shown in the figures here is often invisible on the surface. Even when tapping with a mallet or ordinary hammer on the surface, the wood sounds intact.

If the center part of such a cross section is mechanically separated from the outer part of the stem (by ring-shake decay, for example), it cannot transmit stresses within the cross-section under bending or torsional loading (regardless of wood condition in the center). Parts of the cross-section that cannot transmit stresses do not contribute to the load-carrying capacity of the cross section under wind loading. By visualizing the outer intact and mechanically inter-connected parts of the cross-section (in green), the tomogram thus reveals the most critical aspect of cross-sectional stability (because location of damages is more important in terms of strength loss than just their size, Rinn 2011). That means in such cases, the red dot in the center of the tomogram does not reveal local wood condition in this area, although its presence is good for tree safety evaluations.

High resolution electronically regulated resistance drilling profiles show a clear drop of the profile in the decayed early-wood zone (**Fig. 7**) but at first glance, the profile looks nice and most arborists would evaluate the condition to be nearly perfect. Even with several drillings on the same level it would be nearly impossible to be sure about whether it is a ring-shake decay and if this decay partially or completely disconnects the center of the cross section from the outer parts. Currently, this information can only be determined by sonic tomography in a non-destructive way.

Luckily for tree-safety experts, the center parts of a cross section do not contribute as much load-carrying capacity as the outer parts. But, detection of ring-shake decay should be followed by the recommendation for regular re-inspection with a time interval depending on species. In our practical experience, thin ring-shake decay developed into strong and significant decay over decades in *Castanea*, but much faster in *Sequoiadendron giganteum*.

Figure 7. Profiles of high-resolution, electronically regulated resistance drills mainly reveal local wood density at the point of the needles tip (Rinn 1988) while penetrating the tree. In such profiles, deteriorated early-wood zones are usually clearly visible by a corresponding drop (here marked with a red circle). In addition, this profile shows that the internal wood is intact and of higher density due to the age-trend effect typical for ring-porous species, like this *Castanea sativa* (Rinn 2012). The top curve is a magnification of the bottom one for better visibility in the field.



For usability, evaluation of potentially high value forest trees, detection of ring-shake can be critical, because usually there is no external symptom indicating this internal defect. The industry is concerned about this problem because when someone wants to cut veneer or beams out of a stem with ring-shake defects, they fall apart and are largely useless.

Conclusion

As soon as there are significant central defects, the sonic tomogram does not represent overall local wood condition, but mainly visualizes the parts of the inspected cross section that are intact and mechanically inter-connected, and thus contribute to the load carrying capacity. This information is most critical for tree-safety evaluations (Rinn 2013).

The tomograph system usually cannot reveal the condition of the wood in the area that is mechanically disconnected, and thus marked as red (or purple). Profiles of high-resolution resistance drills reveal wood condition in such mechanically disconnected areas, too, but cannot detect the circumferential extension of ring-shake like defects. These (physical and principle) limitations have to be regarded when using such technical diagnostic devices.

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