DETECTION OF DECAY IN TREES WITH THE METRIGUARD STRESS WAVE TIMER

by Claus G. Mattheck and Klaus A. Bethge

Abstract. The Metriguard Stress Wave Timer measures the time needed for a stress wave to pass from a hammer blow to a sensor on the opposite side of the stem. A calculated sound speed will indicate decayed or hollow spots within the stem. A table of velocities for healthy trees is given and also some examples showing cross- sections of trees containing defects together with the measured velocities.

The detection of decay in green trees is one of the big problems in the safety assessment of city trees and forest trees near public roads. In the Karlsruhe Nuclear Research Center a new method *VTA* (Visual Tree Assessment) [5] was developed. It is based on the *CONSTANT STRESS AXIOM* which is a general design rule for biological structures [1, 2]. This means that the biological design is shaped in a way which guarantees an even load distribution at the surface of the biological load carrier in time average. No points are overloaded (weak spots!), no points are underloaded (waste of material!). If this optimum design is disturbed in a tree for example by decay or a crack acting locally as a stress riser the tree hurries to restore the constant stress state by repair growth, i.e. by adding more material at the level of the defect. This repair growth mechanism is therefore a warning signal or symptom of a mechanical defect. These symptoms are listed by Mattheck and Breloer [5] and they are related to internal defects (Fig. 1). However, in many cases there is no opening in a tree for looking inside or the vitality of the tree is too low to do much repair growth. In these cases and also in order to confirm and quantify a defect the Metriguard Stress Wave Timer is an excellent tool to get a global assessment of the situation (Fig. 2). In the past, the hammer was mainly used for inspection of timber or construction wood which was relatively easy, because no bark had to be penetrated.

At the Nuclear Research Center it was found that the best way to bring the impact through the bark without any loss is through the use of screws. When screws are used the mechanical stress runs into the wood at different levels defined by the thread of the screws. Thereby the punching forces are axially distributed along the shaft of the screw (Fig. 3). Softwoods therefore require a longer part of the screw shaft inside the wood, whilst in really tense hardwoods (beech and oak), one cm wood penetration is sufficient in order to avoid punching of wood fibres.

Although the wall thickness (width) of healthy wood cannot be determined with this method, a rough measurement of the extent of decay can easily be done (Fig. 4). The damage to the tree is acceptable as the screws normally will not pen-

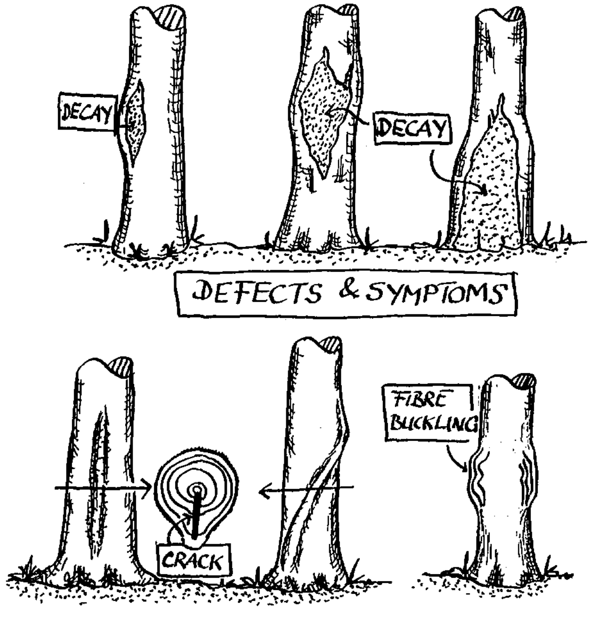


Fig. 1. Some defects in trees and related symptoms

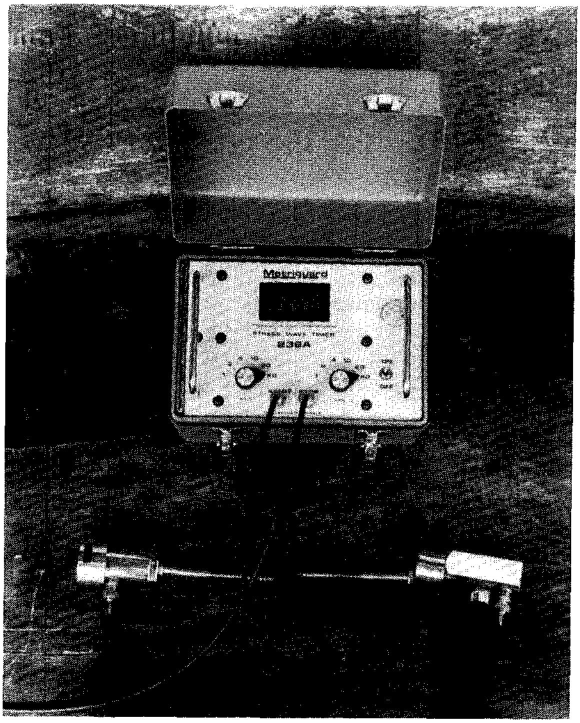


Fig. 2. The Metriguard hammer, sensor and stress wave timer together with the screws ready for detection of decay in trees.

etrate the heartwood and the sapwood usually is able to fight decay quite well. In the following section the results of our field studies are shown together with some defects in cross- sections in order to give the reader an idea how much the different defects will reduce the speed of sound.

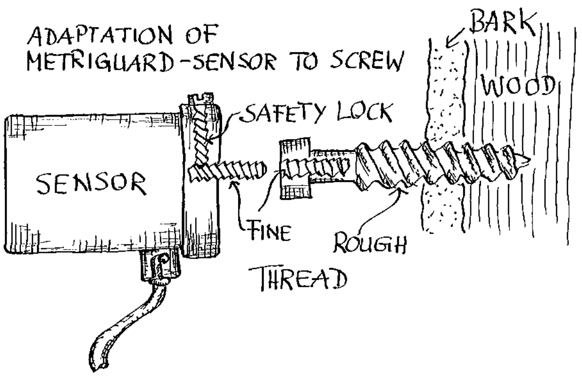


Fig. 3. Only by use of screws can the punching of wooden fibers be avoided.

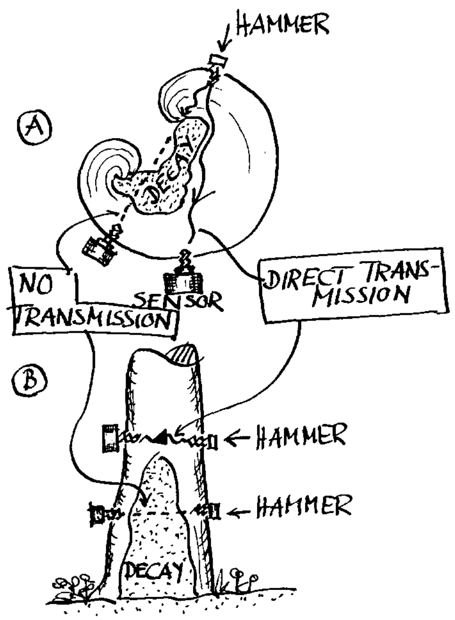


Fig. 4. How to measure the extent of decay inside the tree A) in radial direction. B) in longitudinal direction.

Results and Discussion

In order to assess a tree defect one has to first know which value of sound velocity a healthy tree of the same species would have. That was determined in a field study [3] and the result is listed in Table 1. The velocity is determined by the ratio of the distance between the screw tips by the time measured. As Table 1 shows there is a slightly increasing speed with increasing stem radius, which might be explained by the higher percentage of heartwood in thicker trees' stems, through which the sound might pass more easily. Furthermore Table 1 shows, as a rule of thumb, that velocity in softwoods is about 1000 m/s and in hardwoods about 1500 m/s.

The question to be answered was, what happens in a tree containing a defect? Is the method good enough to detect decay, a crack or encased bark before the tree becomes hazardous? No general table can be given as each defect has to be assessed individually. However, it will be shown that the method will provide the user with very good general information on how dangerous the tree might be. Fig. 5 shows in a self explaining manner the reduction of sound velocity due to the presence of freeze or frost cracks. As we have seen in Fig. 1 these cracks are indicated by rib (callus) formation at the exterior surface.

The sound normally cannot pass through the crack if the crack is gaping. Therefore the stress wave will travel through the sound wood around the crack (Fig. 5B). If, on the other hand, the stress wave runs parallel to the crack, it doesn't have to pass through the crack face. No deviation is necessary and the sound may travel the direct way (Fig. 5A).

As the velocity is the ratio of the shortest distance measured between the screw tips devided by the traveling time, the crack will lead to minimum velocities when sound deviation is most drastic as shown in Fig. 5B. In many cases the orientation of the crack can be seen from outside by observing rib formations (Fig. 1, 5).

Loose tree rings or ring shakes act like concentric cracks and force the sound to travel along the outer circumference of the crack ensemble. This also leads to drastic reductions in the velocity. Fig. 6 shows a chestnut tree with a speed that is 21% of the value of healthy wood.

The most frequent type of defect (decay or hollowness) also has been studied with the Metriguard Stress Wave Timer (Fig. 7). It seems that further investigation of the cross-section is suggested when the velocity is less than 70% of the normal value of healthy wood. In this case an

Table 1: Radial sound velocities in green and healthy trees.

Hardwoods	
maple	1006, 1082, 1103, 1136, 1426
birch	967, 1023, 1026, 1077, 1150
sweet chestnut	1215, 1375
oak	1382, 1416, 1430, 1450, 1495, 1500, 1610
ash	1162, 1210, 1210, 1214, 1218, 1227, 1379
lime	940, 1008, 1061, 1073, 1183
plane	950, 1033
poplar	967, 1090, 1144
black locust	934, 1088, 1100, 1184, 1463
red beech	1206, 1228, 1286, 1371, 1377, 1410, 1412
horsechestnut	873, 921, 1103, 1146
black poplar	869, 943, 1034, 1042, 1048, 1057
silver poplar	821, 950, 1016, 1108
willow	912, 1028, 1155, 1216, 1333
Softwoods	
douglas fir	950, 1013, 1030, 1091, 1209, 1295, 1323
spruce	931, 972, 1040, 1048, 1056, 1085
pine	1066, 1073, 1122, 1132, 1146
larch	1023, 1159, 1238, 1338
fir	910, 938, 996, 1100, 1166

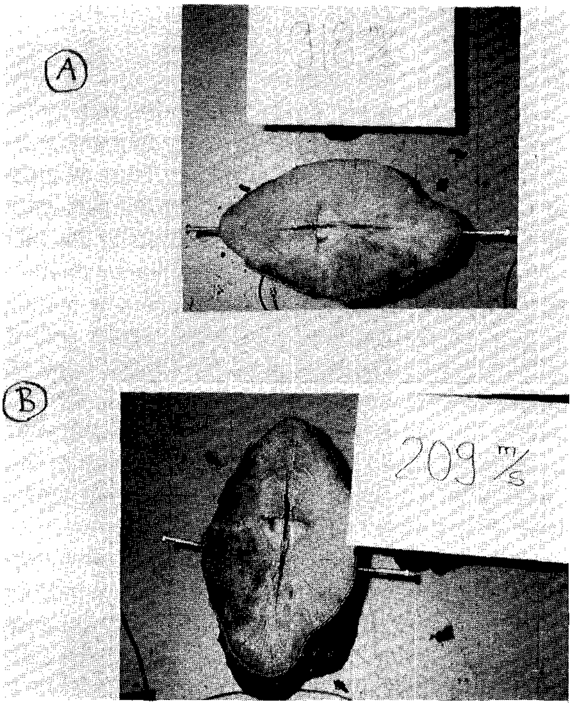


Fig. 5. Cracked cross sections. A) No drastic reduction in sound velocity when the stress wave is running parallel to the crack. B) Drastically reduced sound velocities when the stress wave has to be deviated around the crack.

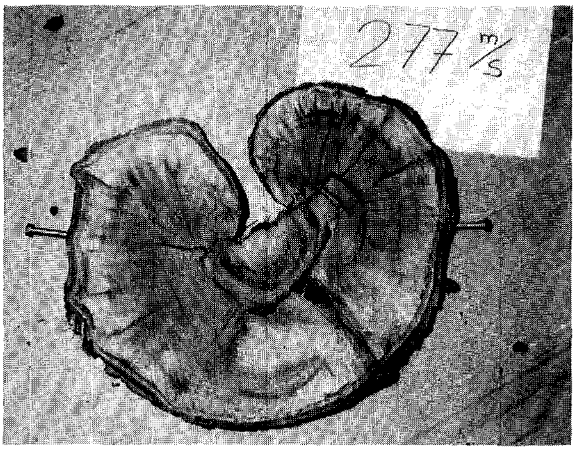
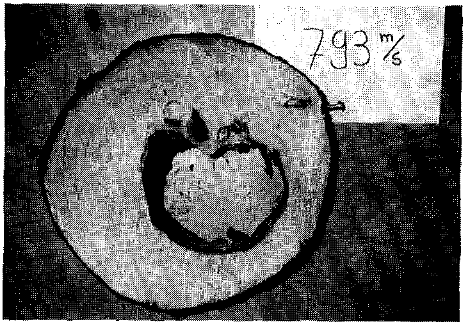


Fig. 6. Drastic reduction of effective sound velocity in a sweet chestnut tree due to multiple decay expanding along the tree rings leading to an ensemble of concentric cracks.

(A)



(B)

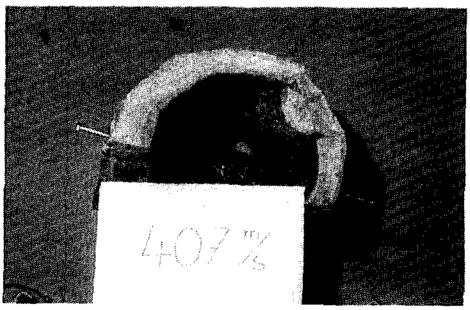


Fig. 7. **Hollow or decayed trees lead to significant reduction in velocity when the defect is large enough. A) Decay in spruce reduces the speed down to 66% of the value for sound wood. B) Hollow beech with only 27% of the normal velocity for sound wood.**

increment driller can be used to check the remaining wall thickness (t) to be below the critical value. We [4, 5] have shown that this value is given by a *critical wall thickness (t) to stem radius (R), a ratio* of

$$t/R \sim 0.3.$$

Trees with values of t/R= 0.32 with fully developed crowns (and therefore maximum crown sail) may break, as a large field study on nearly 800 trees covering a lot of different species has shown (Fig. 8).

Since the wound caused by use of an increment driller is more destructive to the tree, it is recommended that the Metriguard hammer or *similar equipment be used for preliminary confirmation* of significant defects before using the drilling methods in valuable trees. However, if the sound velocities measured are very low, the re-

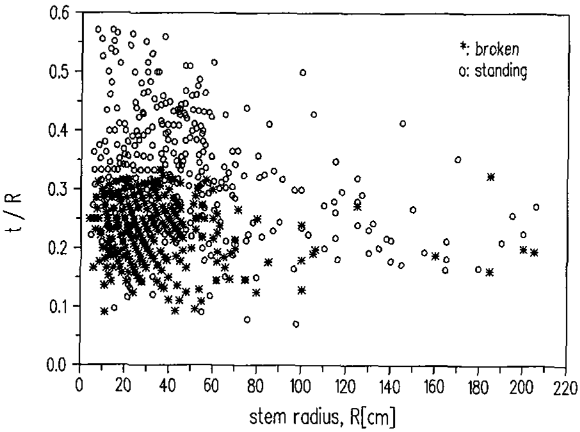


Fig. 8. Ratio t/R of sound wall thickness t normalized by the radius R and plotted versus the radius in cm. Failure occurs for t/R < 0.32.

maining wall thickness of healthy, strong wood *should be determined by use of an increment* borer.

Conclusions:

- The safety of trees can be assessed by measuring sound velocities in a straight forward manner and the results are very reliable.
- The Metriguard Stress Wave Timer in combina*tion with screws is an excellent tool even under* rough field conditions.
- The method is acceptable since there is limited damage to the sapwood of the tree.
- The successive application of 1) observation (looking for defect symptoms [5]), followed by 2) sound measurements (if there are alarming signals) is an inexpensive method of assessing trees near public places.
- Preliminary observations and data have shown that root rot also can be detected if it extends into the butt through application of the Metriguard equipment at the base of the tree, just above the ground.

Warning:

Since the speed of sound is related to the elastic modulus and the density of the wood, the effect of decays that lead to embrittlement (reduction of strength but not stiffness) cannot be detected with the Metriguard hammer, at least in early stages of decay [6]. Such a type of decay is caused, for example, by *Hypoxylon deustum* .

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Zusammenfassung. Das Metriguard- Laufzeitmeßgerät mißt die Zeit, die eine Stoßwelle, welche mittels eines Hammerschlags auf einer Seite des Baumes gestartet wird, benötigt um auf der gegenüberliegenden Seite des Baumes einen Sensor zu erreichen. Eine berechnete fiktive Schallgeschwindigkeit zeigt faule oder hohle Bereiche im Stamm an. Eine Tabelle mit Schallgeschwindigkeiten für gesunde Bäume wird neben ausgewählten Beispielen von defektbehafteten Stammquerschnitten mit zugehörigen Geschwindigkeiten gegeben.

Résumé. L'ensemble Metriguard Stress Wave Timer se compose d'un marteau à impulsion qui émet une ondulation sonore sur un côté de la tige d'un arbre (tronc, branche) et d'un capteur placé de l'autre côté de la tige. Le temps requis pour l'ondulation à passer du marteau vers le capteur au travers de la tige constitue une mesure de la capacité du bois à transmettre le son. Une variation dans la vitesse du son indiquera la présence de zones cariées ou de cavités à l'intérieur de la tige. Une table de vélocités du son pour les arbres sains est donnée ainsi que certains exemples montrant des sections transversales d'arbres renfermant des défauts avec les mesures correspondantes de vélocité.