PLANTS
IN URBAN AREAS AND LANDSCAPE

ADVANCED TREES ASSESSMENT TECHNIQUES – POSSIBILITIES AND LIMITATIONS

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It is the responsibility of land managers to ensure safety of users. This obligation also applies to public administrators responsible for urban forests. People professionally dealing with trees have often conflicting opinions about the use of modern technology for responsible safety recommendations. Knowledge of its applicability is crucial especially for making decisions about mature, ancient and veteran trees. The most popular devices have their strengths and weaknesses. The ability to use it without proper interpretation of the obtained results may lead to wrong conclusions and thus the decisions made. The work was based on analyses of the applicability of selected methods and was supported by two case study examples from practice. The use of diagnostic equipment has been discussed. Instrumental diagnosis supports the correct assessment of trees, but requires a sufficient knowledge and experience in selection of the needed information and interpretation of obtained results.

Keywords: risk assessment, Visual Tree Assessment, Resistograph, Tomograpf, Pulling test (SIM), Dyna Root

1 Introduction

For the purposes of the VTA method, a number of tests were carried out to determine the thresholds for the dangerous loss of mechanical strength of the trunk (Niklas 1992). In connection to the above, more complex equipment and software are used in the diagnostics of trees as a support for safety recommendation (Hayes, 2002). The characteristics of the most frequently used equipment and limitations are presented below.

One of the most popular devices is a tomograph, which allows the assessment of the location and extent of defects in a trunk (Chomicz, 2007; Nicolotti and Miglietta, 1998). Acoustic tomography is a test that uses sound waves to obtain a digital map of wood density (tomogram) in living trees. Similarly, ultrasonic tomography allows reconstructing the structure of the trunk by the distribution of the velocity of ultrasonic propagation within the investigated section even in early stages of wood degradation (Bucur, 1985; Wilcox, 1988; Bauer et al., 1991). In research, a decay characterized by a mass loss of only 15% was clearly detected (Nicolotti et al., 2003). In all cases, computer simulation allows the image of the interior of the tree to be obtained. Moreover, depending on the speed of sound or ultrasonic velocity passing through wood, it is possible to determine the internal structure of the trunk without the necessity to disturb the sound wood (Chomicz, 2007; Nicolotti and Miglietta, 1998). The sensors should be inserted into the bark of a tree so that they reach wood. Then, the test is carried out by striking the sensors several times with a hammer (Arborsonic 3D: User's Manual, 2017). Electric tomography allows the user to obtain an image of the resistivity distribution on a section of a tree (Shortle, 1982).

The result of the test is a tomogram – a graphical representation of the measurement result. It presents the internal structure of the trunk and allows determining the degree of wood distribution at a given height (Chomicz, 2007). ArborSonic 3D software has the ability to calculate the probability of breaking a tree in the trunk (safety factor) at the place of measurement. The program calculates the safety factor for each trunk cross-section examined and shows which winds are most dangerous for the stability of a given tree. The safety factor in acoustic tomography is calculated as a percentage. Higher percentage means lower risk. Above 150% the risk of fracture is low, between 100% and 150% the risk is medium, and between 100%

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and 50% the risk is high, and below 50% the threat is extreme (Arborsonic 3D: User's Manual, 2017).

The standard device used in the VTA procedure is a resistograph (Denise and Jacobi, 2002). Measurements consist in measuring the resistance created during drilling; the data is then generated giving the picture on the real scale. The resistor allows us to study the degree of wood degradation inside a tree trunk. Data from the resistograph are developed in specialized software and, combined with knowledge about the CODIT model, allow for an accurate interpretation of the degree of wood distribution, location and distribution range as well as the presence or absence of a compartment barrier (Johnstone et al., 2002; Shigo, 1979). In the case of the decayed area, characterized by a low mass loss, the result was less accurately detected (Nicolotti et al., 2003).

Another popular method is the integrated measurement of statics, called SIM (Static Integrated Measurement), and popularly called Elasto-Inclino, too. The method was patented in 1989 by Wessolly, and is considered a group of non-invasive methods. It determines the stability of a tree in the ground and the strength of a tree trunk to break. The basis of this method is subjecting the tree to a load simulating the effects of winds, however, not exceeding 3% of the hurricane strength. The dataset specifying the static properties of a tree species, also referred to as the Stuttgart Stability Catalog, and the computer program used to interpret the results, are constantly updated (Wessolly and Erb, 1998). SIM uses sensors, and elastometers, dynamometers and inclinometers to assess the mechanical resistance of trees.

The important approach based on the reaction of roots and the slash on the actual wind load is the Dyna ROOT method. The result is the safety coefficient of the examined tree. The method uses the actual wind and on that basis calculates reactions of the tree. The lowest wind speed, which is needed for successful investigation, is 25 km/h (8 m/s) (Divos and Szalai, 2002). The inclinometer measures the degree of deflection of the tree in the clutch part during movement. The software calculates safety factor on the basis of information collected from inclinometer installed close to the ground and anemometer. It is possible to obtain a safety factor calculated on the basis of wind speed and the degree of tree deviation in the ground (Dynaroot..., 2017). When the safety factor is above 1.5, the safety level is high, between 1 and 1.5 – medium, below 1 – low (Dynaroot..., 2017).

The above presented set of devices potentially gives information allowing for safety recommendation formulation. The question is wheter all methods should be used for that reason or not – which method is highly recommended to solve problem of risk in particular situations. The aim of the study is to demonstrate the tree risk assessment specificity in the context of specialized equipment use on the example of two case studies.

2 Material and methods

In the risk assessment, the most important issue is correct and incorrect interpretation of obtained data. The paper demonstrates the validity of using advanced tools and diagnostic methods for tree risk assessment, in relation to real cases of trees. The use of devices such as: resistograph, tomograph, Integrated Static Integrated Measurement (SIM) – pulling test and DynaRoot system is discussed.

In the study there were used twelve sensors ArborSonic 3D equipment from Fakopp Bt, and Picus.

Moreover, the Elasto method was used which examines the resistance of trunks to fracture, and the Inclino method testing tree stability in the ground. Then, the following parameters were determined: Sg – basic strength, Sb – current breaking strength and Sk – stability of the tree in the ground.

The DynaRoot test consisting of an anemometer and an inclinometer was used to determine the dynamic stability of roots. Using the anemometer, measurements of wind speed and its direction were made. In order for the measurement to be correct and the results reliable, the device was located 10 meters above the ground and in the vicinity of examined trees (no more than 1.5 kilometers).

Before final safety recommendation formulation, analyses of tree specifics was made to determine the optimal set of instrumental methods needed to obtain reasonable results.

3 Results and discussion

3.1 Assessment of the usefulness of instrumental methods

In the paper, limitations and suitability were analysed for risk assessment purposes.

Resistograph is a fast method and gives the basis for monitoring the statics of trees. The method presents results (dendrogram with line presenting integrity of trunks) on a real scale. The hole created by the drill is sealed with packed chips. It has been proved that due to the elevated temperature prevailing during drilling, it is not possible to transfer the pathogen (e.g. hyphae of a parasitic fungus) to other trees (Schwarze et al., 1997; Kersten and Schwarze, 2008). In the immediate vicinity of the wounds, discoloration was observed, but it is assumed that it was probably caused by disturbances of water and oxygen movement. No fungal infection was found caused by the resistograph examination (Kersten and Schwarze, 2008).

Acoustic tomography, using ArborSonic 3D, presents accuracy of results of about 84%. This test has its limitations, e.g. cannot be used in the presence of large metal components integrated with the trunk. As was reported in a field work, small trunk diameter (below 40 cm) and ambient temperature below zero are a contraindication to the test – such results are misleading. The test shows the location and size of cavities and decay without disturbing and destroying living wood (Ostrovský et al., 2017). However, decay and cracks in trunks, the two defects of various significance for loss of stability, are presented as a cavity. Moreover, the tomogram may indicate that cavity is bigger than in reality (Ostrovský et al., 2017; Chomicz, 2007; Wang and Bruce, 2008; Smiley and Freadrich, 2004).

Another approach is to determine the root dynamic stability by Dyna Root or static pulling test. In the classical pulling test the necessary force should cause the same pressure on the crown of the tree as the wind with a speed of 118 km/h (33 m/s) and is obtained by pulling the rope attached to the trunk. A 10–40 kN force is required to perform the static load test. The static load test needs a heavy anchor point, e.g. a different tree or a heavy car. The Dyna Root test needs to be accompanied with 10 m high pole with anemometer on the top, no further than 1.65 km from the checked tree. Both methods, however, use very accurate inclinometers (Wang and Bruce, 2004).

The result of the test is the reaction of the entire tree to load. The Dyna Root method reflects the fact that the entire tree is examined in its natural surroundings. The safety factor is calculated based on the wind speed and the degree of tree deviation at the top. The use of natural wind eliminates the need for height adjustment of arborist ropes during the test. However, a wind speed of at least 25 km/h (8 m/s) is needed, which occurs on average once a week, and requires dependence from weather forecasts. Labeling requires more time to do it properly, although testing alone is easier than the classical pulling test. The disadvantage of the method is that it needs several hours of wind at the right speed to complete the test. Insufficient investigation produces unreliable results.

Coming back to the question which method is the best it seems that the essence of the matter is the solution of the problem or diagnosis of the risk assessment or condition of the tree. In the case of old trees, determining the degree of risk may require the use of several methods, adapted to the existing situation and the tree structure. The cases analysed in order to better understand the decision process are given below.

■ **Figure 1:** Two codominant stems of a large *Quercus robur*
Source: Suchocka 2019

Case study 1

For example, the oak (*Quercus robur*) in Figure 1 grows on the area of a private garden. The tree has two codominant trunks with bark included, connection of trunks is 2 m high (Figure 1). The use of the tomograph will not deliver reasonable data, because of the trunk construction – codominant trunks with a bark included – the result will be unreliable (the bark included, similarly like a crack causes that tomography will detect an excessive cavity inside the trunk, that does not exist in reality). Moreover, the trunk is partly connected with the metal fence – wood grows through metal pieces. In this case it is not possible to apply a test like the pulling test or tomograph. The only effective device in this case is resistograph – the result of the examination is the thickness of the sound wood wall. Moreover, that approach allows the monitoring of the tree. Repetition of the test in the next year or in two years will show whether the wall thickness decreases or increases, and allows diagnosis and decision regarding the range of treatments and future safety decisions concerning the investigated tree.

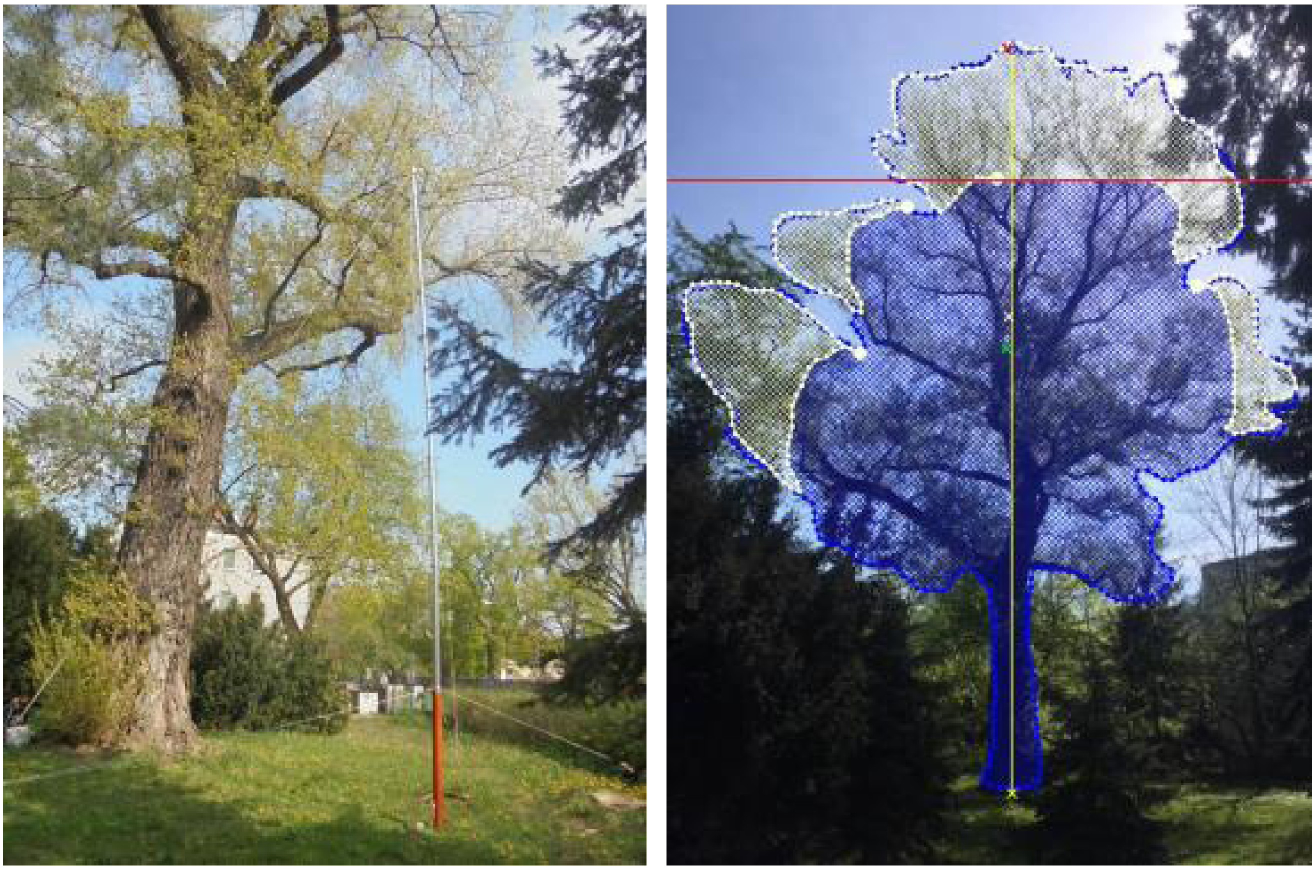
Case study 2

The next tree is a poplar (*Populus nigra*), in which the formulation of recommendations required testing by devices like tomograph, the Dyna Root study, the pulling test and investigation of the buttresses with a resistograph.

The tomography scan was performed at the height of 2 m, a test on the lower level failed due to deep empty spaces between buttresses in the trunk collar and lack of contact between the sensors. At the height of 2 m, the study showed a trunk cavity and caries of 78%. The calculated safety factor was 758%, which gives a low risk of breaking the trunk at the tested height.

The Dyna-ROOT study was performed on three sides – sensors were installed in the root collar from the west, north and east (Figure 2A). The study showed a low risk of falling from the west (safety factor 1.54), moderate risk from the east (1.06) and high risk from the north (0.9). To verify these results, the pulling test was performed. This complementary investigation indicated that in the present state the tree has insufficient value of safety factors, both for breaking and for stability in the ground. The stability factor in soil *Sk* = 1.1 is less than the required value equal to 1.5. The safety factor for a fracture (*Sb*) is 0.9 and its value is also insufficient. The values of safety factors for individual measuring points (measuring instruments) are shown in Table 1. The lowest, insufficient test results are marked in red.

In order to improve the tree's safety parameters, the program indicated the necessity of 40% reduction of its crown in the range shown in the picture below (Figure



A B

■ **Figure 2:** Dyna-ROOT test – visible anemometer (A) and simulation of crown reduction as a result of the pulling test software recommendation (B)

Table 1 Results from the Elasto-inclino test sensors

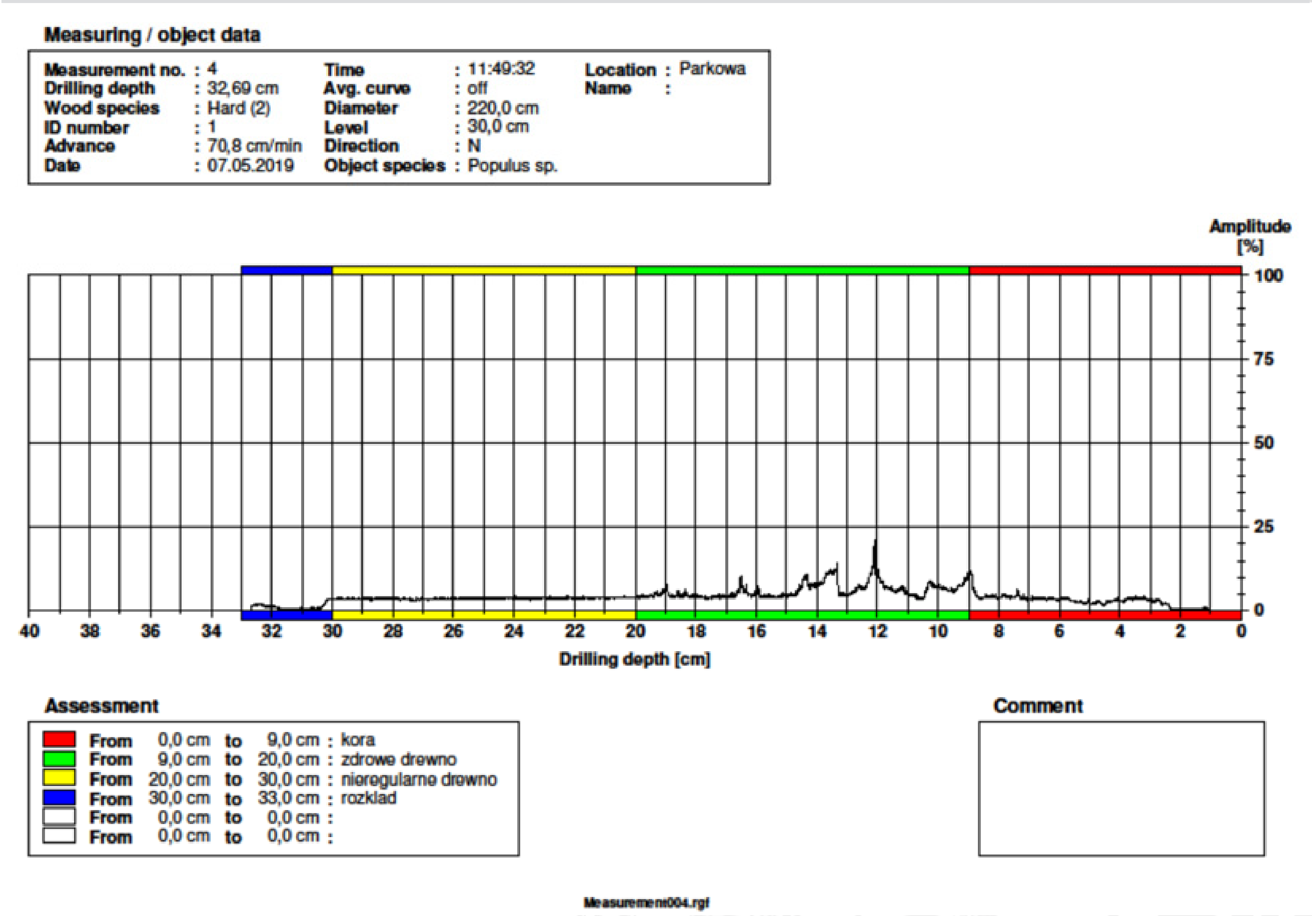
Number of the device	Safety factor
Inclinometer I 1	5.3
Inclinometer I 2	1.1
Elastometer S 1	0.9
Elastometer S 2	1.5
Elastometer S 3	5.2

Source: author's calculations

Table 2 Recomendation for the tree crown reduction

	Before reduction	After reduction
Tree height	34 m	28 m
Crown area	461 m^2	322 m^2
Height of the central point of the crown	20.3 m	17.8 m
Height of the central wind pressure point	21.8 m	19.1 m
Force of wind pressure on the crown	85kN	55 kN
Moment acting on the base of the trunk	1,858 kNm	1,054 kNm

Source: author's calculations



■ **Figure 3:** Drill 4 North-up test – the weakest result from 8 tree buttresses
Source: author's calculations

2B). This procedure would increase the value of safety parameters to *Sb* = 1.6 and *Sk* = 1.9, but such a large intervention would cause the destruction of the tree.

Due to the inconclusive results of both load tests suggesting risk of root collar failure and fear of destroying a valuable tree by excessive cuts to improve the statics, a resistograph was performed on all 6 buttresses of the tree. The study showed the presence of sound wood without decomposition from the east and north-east (more than 35 and 33 cm of sound wood wall) and 22 cm of remote wood on the second on the east side.

The study of both buttresses (No. 5 and 6) from the west also did not show caries over the entire length of the measurement (38 cm). Only one of the six tested buttresses – from the north (Figure 3) showed traces of weakness – 11 cm of healthy wood and 10 cm of irregular wood. The positive results obtained in the root collar resulted in the recommendation of retrenchment cutting to remodel the crown of the tree (a natural reduction of its centre of gravity), which is still possible, and its regular monitoring.

Risks in urban areas cannot be accepted; on the other hand, valuable trees cannot be cut based on incorrect results, therefore, the methods described above are used in practice for comprehensive assessment of trees that may pose a risk. The study of Wang and Allison (2007) demonstrated that the representation of a lateral crack inside of investigated oaks provided by the tomography was similar to cavity inside the trunk and in that case resistance microdrilling tests made the result of the test realistic. The difference between decayed wood and crack-induced acoustic shadows was not a representation of the internal condition, which is crucial for appropriate failure risk classification. Similar conclusions come from the conducted studies. To reduce the number of necessary tests, the assessment should be carried out by a competent person with relevant experience (Suchocka et al., 2019). In case of difficult trees all methods could be recommended to get relevant results of investigation. The proper set of devices for tree risk assessment depends on the situation. For example, the SIM method, due to the multifaceted nature of the information received, seems to be a very good tool, but as shown above, the results of the survey may require verification in order to make a responsible decision. A test with a resistograph or a CT scanner may be insufficient to obtain complete information of tree stability. Studies report that tomography is able to point accurately revealed general location and magnitude of defects, but often in tree investigation, drilling is required to locate the defects and differentiate between decayed wood and crack-induced acoustic shadows (e.g. Wang and Allison 2007). In some cases more testing could be needed, such as results obtained during the pulling test (performed in windless weather) or the Dyna ROOT, which in turn must be done with the right wind. The decision about the way of investigation should be taken after a careful inspection of a tree.

4 Conclusion

Each tree presents a different phytostatic situation and therefore, requires an individual approach. It is not possible to adopt the only proper procedure, the application of which will provide enough information to make a decision in terms of risk mitigation.

The selection of the right method depends on the experience of the person conducting the study, aware of the limitations that are associated with each of them in terms of data interpretation by the device, and limitations associated with the construction of the tree. An example of limitation is CT examination that shows a general picture of the distribution within the trunk, but in case of cracks or bark included the distribution of cavity it is incorrectly shown. In case of result interpretation doubts there can be used a resistograph that demonstrates the sound wood thickness and allows for monitoring of the cavity. The ability to precisely check the wall thickness of healthy wood using a resistograph is crucial for the monitoring of the tree risk.

Each tree presents a different phytostatic situation and therefore, requires an individual approach of an expert. The only correct procedure in the field of testing with use of specialist equipment cannot be assumed in advance. Visual investigation leads to a decision on the selection of a proper device to provide enough information to make a risk mitigation decision.

For many trees, visual assessment is sufficient for risk assessment. However, valuable and at the same time difficult trees (e.g. ancient or aged trees) may require the use of many methods, or even all available ones, that allows us to take reasonable decisions and monitoring, resulting in their preservation for a long period of time, without incurring unnecessary risk by the assessor.

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