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Adapted VTA and SIA method in tree static assessment with use of resistography

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List of nonstandard abbreviations:

CODIT – Compartmentalisation of Decay in Trees
SIM – Static Integrated Method
SIA – Static Integrated Assessment
VTA – Visual Tree Assessment
SW – Sound wood
DBH – Diameter at breast height
BS – basic stability according to SIA mehod

Key words: tree risk assessment, tree failure, Visual Tree Assessment,Static Integrated Assessment, resistograph

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Abstract

Background and Purpose: *This paper introduces a method for assessment of static safety by using the combination of adapted VTA and SIA methods and a resistograph. The aim is to assess the static as reliably as possible and without the need for expensive equipment. The purpose of this paper is to propose a method for the static assessment which could be applied in practice in the future.*

Materials and Methods: *Seven trees in the Botanical Garden of the Faculty of Science (University of Zagreb) were selected for the assessment of vitality and static safety. It has been detected that those trees were affected by possible indicators of decreased vitality, such as fungi fruiting bodies on the root collar or trunk, dead branches, growth malformations, burrs, dead bark etc. The selected trees were: Fagus sylvatica L. »Purpurea Tricolor«, Fraxinus pennsylvanica Marshall, Acer pseudoplatanus L. »Leopoldii«, Fagus grandifolia Ehrh., Quercus petraea L., Quercus phellos L. and Salix alba L. The static stability of the said trees was assessed using a combination of the following three methods: i) adapted VTA (Visual Tree Assessment) method; ii) SIA (Static Integrated Assessment) method; iii) resistograph measurement using IML-Rezi F-300. The height of each tree was measured using the Vertex device, while their diameters were measured using a measuring band. The trees were examined for external symptoms indicating their vitality. The crowns were observed using the Pentax XCF (12x50) binoculars. Afterwards, based on the basic data on the trees, the minimum thickness of sound wood (SW) necessary to maintain the static safety was determined using a computer program. The obtained data were then used to determine the manner in which and the place where the diagnostic instruments shall be used.*

Results and Conclusions: *Based on the knowledge of the subject trees and the measurement of their diameters and heights, SW, as well as the basic safety of trees was determined using the SIA method which was 140% to 410%. For all selected trees, the required safety was 100%, so SW minimum requirement for intact wood ranged from 4.4 cm for the maple to 9.4 for the oak. The resistograph measurements of the 7 assessed trees established that four complied with the requirements, while the American ash, the white willow and the sessile oak were decided for cutting down. The decision was made based on the median measured values, which were below the threshold determined by the SIA method. The sessile oak demonstrated the highest non-compliance, since it scored only 37.0% of the value required for intact wood. The willow scored 48.7%, while the ash scored 62.5%.*

The results of the resistograph measurement were compared to the r/R ratio. Those results show that there was no difference between the two methods, although the weak point of r/R ratio could be clearly shown in relation to future decay development in measured trees.

INTRODUCTION

Wood of a standing tree affected by decay decomposes and gradually loses its ability to bear tensile or compressive load. This consequently leads to the alteration of the triangle of statics which, under certain conditions, may become dangerous given the possibility of tree breaking or overturning *(1)*. Breaking and overturning of trees mostly occur in bad weather conditions, but they are also possible when there is no wind or precipitations. While the potential of causing material damage or injuries to passers-by is insignificant for trees growing in rain forests, forests, parks and rows by the road, it is at its highest for trees growing in city centres *(2)*. The first step to assess general condition of the tree is to perform a detailed inspection of the tree's health using the visual tree assessment method (e.g. 3). After having detected the symptoms through a detailed examination of tree parts, all anomalies are noted and summed up in order to obtain the first impression of the tree's health condition or vitality. Some symptoms clearly indicate problems which endanger the tree's survival, thus giving us a clear prognostic image, while others have no significance in that matter. For instance, fungi fruiting bodies (sporocarps) are a good indicator of spreading wood decay *(4)*. However, the presence of wood-decaying fungi fruiting bodies is not always a symptom of significant wood decomposition or static safety failure. Through their evolution and co-evolution with the fungi, the trees have developed a defence system called compartmentalisation, usually explained by the conceptual model CODIT (Compartmentalisation of Decay in Trees) *(5)*. In order to determine the species of the wood-decaying fungi, identification of fruiting bodies is crucial. The type and biology of the species of wood-decaying fungi tells us about its aggressiveness (*4, 6, 7, 8*). Besides the species, the position and number of fruiting bodies also represent relevant data *(6, 9)* for the primary assessment of decay spreading in the tree. Although some authors consider that this is sufficient to assess the statics (e.g. *4, 8*), this is very difficult to apply in practice, given the need for the extremely vast knowledge of wood-decaying fungi species. Therefore, in most cases it is impossible to answer the question whether the tree is so weak that it represents a risk by using only the visual method.

So as to avoid undesired consequences in the assessment of statics, it is necessary to use additional instruments, i.e. diagnostic devices. There are several types of instruments used for that purpose. They work on different principles but they all have in common the fact that, regardless of their specific operational mode, it is necessary to visually inspect the tree first in order to determine the place and manner in which those devices will be used. There is a large number of methods and instruments *(1, 8, 10)* used, and the assessors do not always use the same scheme *(11)*. The so-called t/R ratio (where t is the radial thickness of sound wood and R the radius of the stem), developed by Mattheck and Breloer *(12),* is often used in practice. The requirement t/R>0.3–0.35 was not scientifically evaluated as good *(13)*: its big flaw is its universal approach, since the method does not take into account the species or height of a tree or the form of its crown *(14, 15)*. Unlike this universal approach, the two methods developed based on the work of Sinn and Wessolly 1989 *(16)* integrate the tree dimensions, wind, tree species and crown form: Static Integrated Method (SIM), and the simpler Static Integrated Assessment (SIA). Since the SIM method is based on the use of some expensive equipment, SIA was developed from a series of SIM method tests aimed at assessing the basic stability based on the measured parameters *(17)*.

There is no unique standard in safety assessment *(18),* so the assessor chooses the assessment method. Errors made by bad assessments are frequent and the subsequent damage is the following:

i) trees which are still statically stable and viable are cut down;

ii) unstable trees, which then break and cause damage, are left.

This problem is especially important in regards to the protected trees, since they cannot be preventively removed without a quality assessment.

No researches concerning this problematic have been conducted in Croatia. The first assessments of statics using instruments were performed on protected trees such as lime in Petrinja *(19)*, aspen in the Krka National Park *(20),* pedunculate oak in Sisak *(21)* or oriental plane tree in Trsteno (V. Lochert – personal communication).

The paper presents the method for the assessment of static safety by using the combination of adapted VTA and SIA methods and resistography. Such researches are lacking in Croatia, while the methods and instruments are rapidly evolving in the rest of the world. So we are looking for an answer to the question how to assess the statics as reliably as possible and without the need for expensive equipment. The purpose of this paper is to propose a method for the statics assessment which could be applied in practice in the future, based on the sample of seven trees in the Botanical Garden of Faculty of Science (University of Zagreb).

MATERIALS AND METHODS

Seven trees in the Botanical Garden of the Faculty of Science (University of Zagreb) were selected for the assessment of vitality and static safety. Those trees were affected by indicators of decreased vitality, such as fungi fruiting bodies on the root collar or trunk, dead branches, growth malformations, burrs, dead bark etc. The selected trees were:

1. *Fagus sylvatica* L. »Purpurea Tricolor«, a cultivar of the common beech (specimen 2221) which grows on the little field no. 23, in the western part of the arboretum, next to the old Mediterranean Rockery. In early spring, this cultivar of the common beech gets bright green leaves with pink margins which later turn dark red. This cultivar is available in plant nurseries, but developed specimens are not common in parks or tree rows. Data on the origin of

this specimen were lost, but it is considered that it was acquired from a domestic plant nursery in the early 1950s.

2. *Fraxinus pennsylvanica* Marshall, red or Pennsylvania ash (specimen 2212a) which grows on the field no. 50, in the south-western part of the arboretum. It is located less than a meter from ground of the eastern black walnut (*Juglans nigra* L.). This species was introduced to Croatia a hundred years ago as an ornamental plant used for afforestation. Data on the origin of this specimen are not known, but it is certain that it was grown from seed obtained from some foreign botanical garden after the Second World War. It has been evaluated as fifty years old.

3. *Acer pseudoplatanus* L. »Leopoldii«, a cultivar of the sycamore maple (specimen 2039) which grows on the field no. 35, in the southern part of the arboretum. This cultivar was selected in 1864 in the Belgian plant nursery Vervaene and named in honour of the Belgian king Leopold I. It is characterized by its leaves spotted and shaded in yellow-white. Although it is one of the older cultivars of sycamore maple, it is not common in Croatia. This specimen was planted in 1960s, but its exact origin remains unknown.

4. *Fagus grandifolia* Ehrh., American beech (specimen 749b) which grows on the field no. 7, in the eastern part of the arboretum, next to the systematic field. This American species is rarely planted in European parks and gardens, mostly due to its sensibility to alkali soils. This is also the reason why there are no cultivars thereof. By its size, the said specimen is one of the largest and tallest trees in the Botanical Garden. Although the data on its origin were lost, it most likely remains from the original collection planted in the late 19th or early 20th century.

5. *Quercus petraea* L., sessile oak (specimen 1289a) which grows on the field no. 8, in the south-eastern part of the arboretum, next to the collection of perennials (spectrum). The specimen belongs to the group of several trees pertaining to the same species. There are no detailed data on their origin. They were probably planted when the collection was renewed after the First World War.

6. *Quercus phellos* L., willow oak (specimen 2409) which grows on the field no. 8, in the south-eastern part of the arboretum, next to the main path. This North American species is known for its long leaves with an entire margin, similar to willow leaves. Sometimes it is planted in the European parks as a solitary tree (although it is rare in Croatia). The specimen was grown from seed, but there are no data on its origin or age. It is assumed that it was grown after the Second World War.

7. *Salix alba* L., white willow (specimen 5475) which grows on the field no. 9, in the eastern part of the arboretum, next to the little lake. The white willow is autochthonous in our lowland forests, and it is generally related to wetlands. Its age is unknown, and the tree has been listed since 1975.

The static stability of the said trees was assessed using a combination of the following three methods:

i) adapted VTA method; ii) SIA method; iii) resistograph measurement.

The purpose of combining the three methods is to establish, with as much precision as possible, the actual condition of trees and their load bearing ability.

The height of each tree was measured using the Vertex device (Haglöf, Sweden), while their diameters were measured using a measuring band.

The trees were examined for external symptoms indicating their vitality. Afterwards, based on the basic data on the trees, the minimum thickness of soundwood (SW) necessary to maintain the static safety was determined using SIA tables. The obtained data were then used to determine the manner in which and the place where the diagnostic instruments shall be used.

Adapted VTA Method

The VTA method (Visual Tree Assessment, 3) adapted according to Pernek 2011 *(21)* comprises integrated tree diagnostics based on wood biology, damage symptoms on individual parts and assessment of the vitality of the whole tree. The assessment of the trees' health condition by visual method was performed on 5th and 9th September 2012. Their height and diameter at breast height (DBH) were measured on the same occasion. The crowns were observed using the Pentax XCF (12x50) binoculars.

A tree's condition is holistically considered, taking into account all individual symptoms, such as bark state and colour, presence of flux, tumours, growth malformations, fungi fruiting bodies *(22)*.

SIA Method

The SIA method is based on the data of Wessoly and Erb *(1),* obtained by the pull test performed on a larger number of trees. This method comprises all three elements of static: load (weight), form (crown form) and material (tree species). It is used to assess the basic safety of a tree by comparing the weight upon the crown with the strength of the trunk wood and root. The SIA method calculates the force generated by Beaufort scale 12 hurricane force wind. The elements of the triangle of statics differ considerably between tree species and between individual trees, depending of their habitus and dimensions.

Resistograph Measurements

The resistograph measurements were performed using the IML Rezi F-300 (IML, Germany) device on 23rd and 24th September 2012. Based on the VTA, i.e. based on the presence of sporocarps and other visible symptoms on individual trees, it has been decided on which places the tree shall be examined *(23, 24)*. The drilling was performed using the drill bit of 30 cm in length and 1.5 mm in diameter. The number and position of the drilling holes was also determined by VTA. The first drilling hole was always on the north side, while the others were positioned at determined intervals clockwise from that spot.

TABLE 1

Tree health (vitality) assessment in the Botanical Garden of the Faculty of Science (Zagreb University) using Visual tree assessment method (VTA). H – measurement hight, d – trunk diameter at breast height, N – number of drillings with resistograph.

Tree species	VTA	Resistograph
Fagussylvatica 'Purpurea'	Overall, the tree vitality is good, although many symptoms in the root collar zone indicate problems in the normal functioning of the vascular cambium (bark necrosis) and root system (dark sticky fluid). Longitudinal crack in the trunk seems to be well compartmentalized disabling penetration of rot fungi. Fruiting bodies of fungus *Mycena* sp. was detected on the northern side of the top wound margin towards the fork. The size of the wound on the southern side of the trunk could enlarge and root collar bark could crack in the future due to no compensation growth. So far, top dieback (of branches and twigs) as an indicator of nutrient supply and transport problems, is not present. Thereby it is estimated there is no additional tree vitality loss.	Measurement around wounds H=1,80 m d=75 cm N=6
Fraxinus pennsylvanica	Heavily leaned ash tree of low vitality, indicated by trunk oozing spots, dead branches, low crown density (crown fading), and initial pest assault. Due to lower trunk large longitudinal wound and wood decay within, tree has developed compensation wood around wound margins to improve stability. The wood decay is advanced up and down the trunk from the wound.	Measurement around the open wound H=1,30 m d=51 cm N=6
Acer pseudoplatanus 'Leopoldii'	Tree vitality is satisfactory, though several symptoms indicate problems (bark necrosis, decay fungi fruit bodies). Longitudinal crack in the trunk seems to be well compartmentalized disabling penetration of rot fungi. *Xylaria polymorpha* fruit bodies on the root collar might spread. Tree health is compromised, but not at the life-threatening level.	Measurement around the open wound in the root collar H=0,30 m D=77 cm N=8
Fagus grandifolia	Tree vitality is satisfactory, although symptoms like buttress and trunk root collar thickening, decay fungi fruit bodies and week lion tailed branches in the crown top indicate the possibility of an active wood decay process. Roots wood decay process caused by *Meripilus giganteus* will continue, where the speed of progress will depend on many factors such as tree vitality decrease and onset of a strong stressor (e. g. drought, extreme high or low temperatures) which could favour the spread of decay.	Measurement around the open wound in the root collar H=0,30 m d=116 cm N=15
Salix alba	Symptoms such as visible large number of fruit bodies of two species of wood decay fungi (*Ganoderma aplanatum* and *Ustulina deusta*) point to well advanced root wood decay process which poses serious falling danger.	Measurement around the open wound in the root collar H=0,30 m d=44 cm N=5
Quercus petraea	Tree vitality is satisfactory, although symptoms like buttress roots thickening, decay fungi fruit bodies and week, and lion tailed branches as well as trunk deformation like dents indicate an inactivity of the cambium. Fruit bodies fragments found at the buttresses were unidentifiable.	Measurement around the open wound in the root collar H=0,30 m d=60 cm N=6
Quercus phellos	Tree vitality is compromised. Potential stability issues are possible in the open trunk wound area, but it is not possible to determine the direction of wood decay from branches (ascending or descending). Serious problem is posed by the assault of an unidentified vascular disease causing crown dieback and slow decline of the tree.	Measurement around the open wound in the root collar H=1,30 m d=78 cm N=3

Depending on the tree, the drilling was performed at 90° and 45° angles. The drill bit was disinfected, as necessary, if the drilling was performed in rotten wood, so as to avoid contamination of healthy parts.

RESULTS

By visual examination of each individual tree using the VTA method, the primary assessment of the tree's vitality was performed, and major problems which could affect their static safety were detected (Table 1). The intensity of drilling and the position of drilling holes were also determined based on this examination (Table 1). On four trees, the resistograph was used on the root collar, while on the other trees it was used on higher parts, where decay symptoms were detected (Table 1).

Based on the knowledge of the subject trees and the measurement of their diameters and heights, SW, as well

TABLE 2

Overview of tree features and parameters in order to investigate tree statics safety (based on SIA method and required safety of 100%).

Tree species	h (m)	d(cm)*	Crown shape acc. SIA	BS (%)	SW_{min} (cm)	SW_{Med} (cm)	SW_{Med}/SW_{min} (%)	Decision
Fagus sylvatica 'PurpureaTricolor'	16	75	3	270	6,7	28,0	–	safe
Fraxinus pennsylvanica	**17**	51	1	140	8,2	**4,0**	48,7	felling
Acer pseudopltanus 'Leopoldii'	19	77	1	410	3,0	28,0	–	safe
Fagus grandifolia	27	116	4	240	9,3	28,0	–	safe
Salix alba	**13**	44	1	270	4,0	**2,5**	62,5	felling
Quercus petraea	**18**	60	3	220	5,4	**2,0**	37,0	felling
Quercus phellos	29	78	1	180	9,4	28,0	–	safe

* without bark

Abbreviations: h – height of the tree; d – tree diameter at breast height; BS – basic stability according to SIA method; SW – sound wood;

as the basic safety (BS) of trees was determined using the SIA method (Table 2). According to SIA, the BS amount was 140% to 410%. For all selected trees, the required safety was 100%, so SW (Table 2) was determined based on the C SIA diagram *(1)*. This represented the minimum requirement for intact wood. The results were in the range from 4.4 cm for the maple to 9.4 for the willow oak (Table 2). Further to that, a resistography was performed at the specified spots (Table 1), clockwise from the north. The resistograph measurement of the 7 assessed trees established that four complied with the requirements, while the American ash, the white willow and the sessile oak were decided for cutting down (Table 2). The decision was made based on the median measured values, which were below the threshold determined by the SIA method. The sessile oak demonstrated the highest non-compliance, since it scored only 37.0% of the value required for intact wood. The willow scored 48.7%, while the ash scored 62.5% (Table 2).

The results of the resistograph measurement were compared to the r/R ratio (Table 3). Those results show that there was no difference in the final decision between the two methods.

DISCUSSION

From the 1990s, biomechanics have become more and more important in quantifying the forces imposed on trees and their ability to support the load or fail. Often models are developed to simplify complex computations and interaction.

While many of these failures are predictable, there remains a dearth of information on species failure tendencies, as well as the importance of specific tree structural defects, site disturbances, and weather events associated with failures *(25)*. Yet, there has been limited scientific study of which characteristics are important or how to translate what we see into likelihood for failure *(18)*. VTA describes the process of visual assessment *(3)* which should give a clue about internal conditions. This model is widely used *(18)*. Hickman *et al.* 1995 *(26)* found that leaf cover and colour defined as decline was the most important predictive characteristic related to failure. Also important were trunk condition and lean. In our study we can confirm those findings partly. Two trees (*F. pennsylvanica* and *Q. petraea*) out of the seven assessed trees had very bad crown and trunk conditions and were leaned (Table1). Both trees have been decided for removal. *Salix alba*, as the third tree decided for removal, also shows bad trunk condition and was leaned, but the colours and cover of leaves were rather good (Table 1). This is probably related to the presence of the decay caused by *Ustulina deusta*, whose specific attack and symptoms are described *(4)*. Similar to our observation, the destruction of wood could be very extensive before the symptoms and fruiting bodies occur.

Visual assessment is often not enough for the knowledge about internal condition *(18)* related to tree failure. It is a broad area of expertise that combines many disciplines, and there are major gaps in research that are directly applicable to the professional practice *(18)*. However, tree risk assessment evolved greatly in recent years, from ground based visual hazard inspection, through

TABLE 3

Comparison of tree static assessment between SIA and r/R=0,32 ratio (r- radial thickness of sound wood measured by IML-Rezi; R - radius of the stem).

Tree species	r (cm)	SW_{min} (cm)	r- SW_{min}	safe Y/N	R (cm)	r/R	safe Y/N
Fagus sylvatica 'Purpurea Tricolor'	28,0	6,7	21,3	Y	37,5	0,75	Y
	28,0		21,3	Y		0,75	Y
	28,0		21,3	Y		0,75	Y
	28,0		21,3	Y		0,75	Y
	28,0		21,3	Y		0,75	Y
	28,0		21,3	Y		0,75	Y
Fraxinus pennsylvanica	8,0	8,2	-0,2	N	25,5	0,31	Y
	9,0		+1,0	Y		0.35	Y
	3,0		-5,2	N		0,12	N
	3,0		-5,2	N		0,12	N
	3,0		-5,2	N		0,12	N
	5,0		-3,2	N		0,20	N
Acer pseudopltanus 'Leopoldii'	28,0	3,0	+25,0	Y	38,5	0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
	28,0		+25,0	Y		0,73	Y
Fagus grandifolia	22,0	9,3	+12,7	Y	58	0,37	Y
	22,0		12,7	Y		0,37	Y
	19,0		+9,7	Y		0,32	Y
	26,0		+16,7	Y		0,45	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	22,0		+12,7	Y		0,37	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
	28,0		+18,7	Y		0,48	Y
Salix alba	3,0	4,0	-1,0	N	22	0,13	N
	20,0		+17,0	Y		0,90	Y
	1,0		-3,0	N		0,05	N
	2,0		-2,0	N		0,09	N
	2,0		-2,0	N		0,09	N
Quercus petraea	2,0	5,4	-3,4	N	30	0,06	N
	2,0		-3,4	N		0,06	N
	0,0		-5,4	N		0,00	N
	8,0		+2,6	Y		0,26	N
	4,0		-1,4	N		0,13	N
	0,0		-5,4	N		0,00	N
Quercus phellos	28,0	9,4	18,6	Y	39	0,71	Y
	28,0		18,6	Y		0,71	Y
	28,0		18,6	Y		0,71	Y

invasive drilling and resistograph tests, to sophisticated and minimally invasive methods *(27)*. Nowadays wave techniques, micro drilling, stress-wave, electrical resistivity, radar and other techniques are used *(18, 27)*. Most of the equipment and tests have been carried out on a few intact trees, which made it impossible for statistical analysis. None of the used techniques provides a complete picture of wood condition. In our study, VTA gave the basic knowledge of a possible tree failure. Drilling by resistograph in different directions shows the concrete condition, but was not enough to make a decision. Therefore, we need to know the minimum value of SW, which was figured out by using SIA.

Comparing the results of SIA and the r/R ratio (Table 3) show that there was no difference in the final decision. But if we look a little bit closer i.e. *Fagus grandifolia*, the safety threshold in our observation was 9,3 cm (Table 3), while according r/R=0,31 respectively 18 cm. As decay progression for this tree is expected, the r/R ratio rule of 0,32 will suggest to remove the tree when achieving 18 cm, which is 9 cm less that the decay has to overcome based on the SIA. That could mean much earlier removing of the tree. Similar model could be detected in four trees more in this study. This example clearly shows the week points of the r/R ratio, and therefore should be considered in the tree static assessment.

These analyses show an example how to perform tree risk assessment. It is important to recognize that it is not an all-purpose tool because sometimes further investigations such as climbing inspections of crowns are needed.

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