University of West Hungary

PhD Thesis

THE STUDY OF HEALTH AND STATIC INVESTIGATIONS OF TREES IN URBAN AREAS

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1. RELEVANCE OF THE SUBJECT

In recent decades, mankind have been paying increasingly more attention to the natural environment. The immediate surroundings of the residence and workplace, including the green space is subject to growing awareness. Solitary trees planted in urban areas for recreation and protection play an important role in this, because society expects an rising number of infrastructure services directly from trees in urban areas.

These services, such as clean air, shade and other benefits of green space can only be fulfilled by healthy and thrifty mature trees. The age of trees, therefore, should be extended as long as possible, but unfortunately more health problems arise with trees of older age.

The large size of trees brings about increasing negative effects, as well. The falling branches and fallen trees can create a hazard to human life and property, and can cause considerable damage. These trees should be intensively managed and cared for, but the difficulty is that the properties of mature trees, especially the development of biomechanical stability is not well-understood.

The technological advancements of the last two decades helped the development of devices for measuring mechanical stability and internal defects of trees. Several of these instruments are now available to urban foresters and tree care professionals at an affordable price.

The currently used tree testing procedures often forecast the methods and timing of interventions in sparse intervals, so the risk management of trees could be somewhat haphazard. Thus, the interpretation of the results of tree testing require further clarification.

Some of the common tree testing procedures require complicated and significant organizational activity and are costly and time-consuming. It is prudent to reduce the level of expenditures, especially since some costly tree care intervention is only worth it if the subject tree is of high value.

After a thorough review and study of currently known tree testing methods, this paper proposes changes to the procedures to make them more efficient. New tree testing procedures that were developed under this study are also introduced while enhancing the knowledge of static loads of older trees.

2. OBJECTIVES OF THE STUDY

The study of solitary trees started several years ago in Hungary and have been progressing dynamically, keeping up with similar research abroad. The author wanted to answer several research questions by setting the following objectives at the beginning of this study:

The review of available national and international literature is an important starting point to establish a research topic and reference points. In particular, the following priority issues have been identified:

- the role and impact of wood-destroying pests and pathogens in tree resistance, in particular of the tinder fungus;
- the understanding of effects of catastrophic forces to tree equilibrium positions, with special regards to the effects of wind;
- the mechanical characteristics of trees in relation to tree resistance;
- the equilibrium positions of trees;
- the behavior of the stem and roots at the onset of forces; and
- the understanding of technical possibilities and tools for tree inspection.

Following the literature review, it is necessary to carry out many of the available and suitable tree testing procedures by assessing and measuring the mechanical properties of mature trees and their immediate surroundings.

The analysis and interpretation of data from these measurements and observations will enhance the knowledge on the static loads of trees.

The interpretation of data can help in refining methods for determining tree resistance, thereby reducing the risks of decision making, so tree care can be performed more cost-effectively.

Understanding the causes and the course of tree fall may lead to more economical and simpler procedures and faster development of indicators and methods for determining tree resistance.

3. HYPOTHESES

After defining the research objectives, the following hypotheses were formulated:

1. Depending on the shape of the stem of the damaged tree, there could be several sources of random measurement errors when using an acoustic tomograph.

2. Decay can take many different shapes and forms in the stem.

3. Wall thickness below a certain size due to decayed or hollow parts in the stem is no longer sufficient to maintain tree resistance.

4. The resistance of solitary trees in urban areas can be characterized by the slenderness ratio usually applied to forest trees.

5. Diameter at breast height and crown dimensions are statically correlated.

6. A calculation protocol can be developed based on simple instruments measuring the parameters that can provide a cost-effective way to assess the stability of trees.

7. Trees of different species that are uprooted due to a disease exhibit a similar shape of the root system.

8. There are mechanical, statical reasons behind the flares and spreads that form on the lower part of the tree trunk, root collar and roots of older and larger sized trees.

4. RESEARCH MATERIALS AND METHODS

The study of the trees in urban areas took place between 2008-2014. The selection of trees occured randomly, partly based on external assignments and in part because some of the trees appeared to be in risky locations. The trees were of different ages, but most would be considered mature. Ninety percent of the trees are located in western Hungary, including two-third in Szombathely and its surrounding area, partly on streets and squares, as well as gardens, parks, and a small number in rural areas subject to urban and intensive use.

The static tests involved 71 individual trees of 27 species with a full survey that meant the detailed measurement of 23 structurally important features, and the assessment of forces acting on each tree. In addition, five variables for each tree were derived from databases, and ten variables were the results of calculations. These variables together include the scope of the data required for the analysis of tree resistance.

A total of 197 tomographic measurements have taken place, a number of them at multiple heights on the tree. Altogether, 459 trees of 40 species were visually inspected with special regards for crown and stem shape and the root collar. The author’s purpose was the understanding and analysis of environmental relief and its relation to non-measurable characteristics of the tree.

The effective root zone was clearly identifiable for nine trees that were uprooted or moved by wind, so these trees were used to demonstrate a cost-saving tree test procedure developed by the author.

Tree resistance was calculated in MS Excel using input values from data that were either directly measured or obtained from databases as per the above methods. A subroutine within MS Excel was used to calculate wind loads following international standards.

Certain indicators derived from the tree data and correlations among tree variables were calculated using the STATISTICA software package based on non-parametric statistical methods.

5. RESULTS

Mechanical effects due to human activities often result in physical changes to the tree that greatly affect its stability.

Various indicators and ratios derived from measured and calculated data for a given tree can help assess its health and static loads relative to an 'ideal' tree growing under similar environmental conditions. One such indicator is the tree height (m) to diameter at breast height (DBH) (cm) ratio that should be below ½ for trees located in urban areas to ensure sufficient resistance to stem breakage.

The following relationships can be derived from the ratio of DBH to various crown dimensions:

- Tree stability is maintained if the value of crown surface expressed in square meters is less than the value of DBH expressed in centimeters.
- Resistance to stem breakage can be considered sufficient if the crown diameter is less than ten times the DBH.

The relationship of various indicators cannot be described by one statistical curve, rather the data values generally form a band or cloud that exhibit a linear trend as implied by the relationships stated above. However, there is a sudden, usually exponential change at extreme values due to stem breakage or tree fall (i.e., failure in resistance).

Tomographic studies conducted after tree measurements yielded an insight into the relationship between the size and extent of decayed or hollow parts, the remaining wall thickness in the tree and diameter. Although no definite relationship could be obtained, the data provided important information about the extent and bounds of internal defects. The application of tomography at multiple heights along the tree enabled the construction of 3D models of internal decays. The author differentiated four different types of decay shapes: cone, inverted cone, barrel and cylinder-shaped cavity. The analysis of the decay shape gave important information about the starting point of the damage and the short-term outlook for the tree.

Analysis by the author indicated the extraction of relevant data on the remaining wall thickness in the tree using acoustic tomography. Uniform, pipe-like wall thickness of healthy wood comprising at least ⅓ of the stem diameter will ensure sufficient tree resistance. Trees with smaller remaining wall thickness can only be maintained by crown pruning and crown reduction.

Root plate diameter is also an important characteristic and can be interpreted in the context of tree height and DBH. According to this study, tree stability requires that the root plate diameter to be at least 20% of the total tree height.

Analysis of tree survey data combined with the information from tree-pulling experiments, windthrow studies and the thorough review of other relevant literature provided the basis for the development of a tree resistance calculation method that could serve as an alternative to costly and time-consuming experimentation. In addition to the basic tree data, this new method requires careful determination of two very important pieces of information: wind speed and the extent of the effective root system.

6. THESES

1. Measurement data for a given tree obtained by acoustic tomography can vary greatly based on decisions taken by the surveyor.

The results of tomographic measurements can be distorted significantly due to random errors. These errors generally result in an overestimate of tree stability and can be caused by several tree defects such as healthy knots, frost damage, cracks (internal growth, mechanical), burls, plank roots, internal adventitious roots, ribs, tumors, scars and galls, goiters, flares, spreads and overgrown objects.

In addition, in practice it is often difficult to spot the critical cross-section, and the measurement is done elsewhere. It is also possible to assume a circular cross section instead of the real cross section during tomographic measurements or to use less sensors thus significantly reducing measurement time on bigger jobs; however this can become a major source of bias.

2. Based on 3D tomograms, there are four basic manifestations of stem decay.

The 4 stem decay forms are as follows:

Conical decay or cavity is widest at the base of the root. The rot starts at the root collar and it quickly moves upward once reaching the pith. This form of decay is the most dangerous to tree resistance, because it is very likely that the root system is also damaged by the disease.

Rot that starts from a stem injury above the root collar can spread upward, downward and toward the pith thus it usually exhibits a a barrel or spindle shape. Based on the CODIT principle, the pathogen can travel faster in the direction of the tracheids than radially which results in an elongated form of decay that is broader in the mid-section.

Frequent tree pruning or historical pollarding in residential areas cause extensive injuries close to the base of the tree crown thus helping the pathogens get into the stem. In this case, the rot begins to extend downward and to a lesser extent radially resulting in an inverted cone shape. This form of decay increases the chance of branches breaking off the tree.

If the extension of the rot is sufficiently large in the direction of the tracheids, the disease will also start to spread radially. In this case the cylindrical shape of decay create a pipe-like cross section where the living and thrifty sapwood forms the pipe wall. This form of decay most often occurs on horse chestnut.

3. The remaining wall thickness ratio of a decayed or hollow stem where the crown is not managed, must be at least ⅓ in order to maintain sufficient tree resistance.

Tomographic measurements by the author indicate that the stems with a remaining wall thickness ratio of ⅓ or less are susceptible to breakage. However the remaining wall thickness ratio of ⅓ must be uniform along the stem to maintain stability. Values below ⅓ may occur on stable trees with a heavily pruned crown.

4. The ratio of tree height and DBH can take a value as high as ½ for solitary trees without significantly affecting tree resistance.

Based on measurements in this study the heights of trees in residental areas lag behind their counterparts growing in a forest stand under similar environmental conditions. The ratio of tree height to DBH, called the slenderness index must be below ½ for solitary trees to maintain sufficient resistance to stem breakage.

5. The following relationships can be derived from the ratio of DBH to various crown dimensions:

Tree stability is adequate if the value of crown surface expressed in square meters is less than the value of DBH expressed in centimeters.

Resistance to stem breakage can be considered sufficient if the crown diameter is less than ten times the DBH.

6. The author developed a process for calculating tree resistance that could replace costly and time-consuming tree-pulling experiments.

The process is similar to other tree resistance calculations in accounting for stattic loads and forces of resistance and comparing the bending moment to the resistive moment of the tree. The difference is in the interpretation of the individual factors and their calculation methods (e.g., EUROCODE wind load calculation, determination of crown surface, modified aerodynamic factors and the extent of the root zone). This process is particularly suitable for identifying the causes and course of tree fall.

In performing the calculations, the following correlations emerged:

- 10% change in the radius of the root plate will cause 22-25% change in tree resistance in the same direction. In addition, 10% change in the crown surface will bring about 10% change in stability in the opposite direction.
- Spearman's rank correlation showed that tree resistance is mostly affected by the horizontal extent of the effective root zone. One of the most important pieces of data that is also the most difficult to determine is the horizontal extent of the effective root zone. The following important points should be considered:

    - By examining the root system of uprooted trees we can state that the roots that break are generally 5 cm or thinner in diameter.
    - In addition, the surface movements often indicate the bounds of the effective root zone, moreover utilities, building foundations, fences limit the development path of the root system.

- Estimating tree resistance and safety can be helped by the relationship that root plate diameter should be at least 20% of the total tree height.

7. Most uprooted trees exhibit a root zone similar to the shape of the lateral root system.

Uprooted trees examined in this study showed that at older ages the effective root zone closely resembles the lateral root system. Trees that overturn with the heart root usually have a significantly reduced root system due to damage. In case of a well-developed heart root not only the extensive root system prevents overturning but also the high compression strength of the soil on the leeward side of the root zone minimizes movement. Uprooted trees with a taproot are generally regarded a transition to stem breakage since the broken taproot can be considered a continuation of the stem below the ground.

8. Roots rising above the soil surface, flares, spreads and ribs are all mechanical reactions of trees to growing stress due to external forces.

Greater static loads are generated from increasing weight and surface area which result in increased tensile and flexural stress in the root system. However, the increasing stress in trees is not only due to the greater weight and greater crown surface but also by cause of decreasing strength because of the reduction in the cross-sectional area due to decay. Since trees are trying to compensate for the increased stress, they respond by thickening the stem or root collar near the ground that leads to roots rising above the soil surface, increasing spreads, flares and ribs.

7. PRACTICAL APPLICATIONS OF THESE FINDINGS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The material presented in this doctoral thesis has significantly broadened and deepened the knowledge base of tree properties. Information contained in this study can be used in tree registries, during the assessment of green space and in the preparation of inventories. However, first and foremost the knowledge developed in this thesis should help in tree experimentation and testing and in the preparation of more reliable forecasts.

With regards to trees, this thesis clarifies answers in relation to life and property safety issues and provides new aspects for examination. One special consideration is the determination of liability where tree resistance calculations could provide the means for reconstructing the cause, course and partially the consequences of the catastophic failure of a tree even if the subject tree is no longer available.

In addition, this work can be used in planning and estimating the cost of pest control and tree protection measures.

The advancement of information technology helps the creation of efficient measuring devices; however interpretation of the results will still require technical-biological and ecological knowledge of trees.

Of course, these results need to be further developed as we still know little about solitary and mature trees. Still a large amount of data is needed with regards to material properties of the living wood, especially volume and density data of live trees, their different strength values, the mechanical properties of soils and the mechanical interactions of the root system and the soil. More research is needed on wind speed and the changes in turbulance due to increase in the aerodynamic roughness of the surface.

Our profession still struggles with the thorough scientific analysis of cases of domestic windthrow and with the development of effective prevention methods. We do not know enough yet about the process and speed of tree decay for different tree species or pathogens, either.

8. THE LIST OF PUBLICATIONS RELATED WITH THESIS

8.1. Scientific papers (in reviewed journals)

Tuba, K.- **Kelemen, G.** (2010): Bögölyszitkár *(PARANTHRENE TABANIFORMIS* ROTT.*)* csapdázási tapasztalatok dugványtermő anyatelepen és idősebb nyárállományban. Növényvédelem, 46. évfolyam 11. szám, 2010. november, 540-546. pp. ISSN 0133–0829

8.2. Scientific presentations (in conference proceedings)

Kelemen, G. i Tuba, K. (2013): Vetrom spôsobené škody na solitérnych stromoch (Západomaďarská univ. Šoproň, Maďarsko). (Szél által kidöntött szoliter fák vizsgálata) In: Hrubík, P. és Gáperová, S. (szerk.) (2013): Dreviny vo verejnej zeleni. Zborník z konferencie s medzinárodnou účasťou. Nyitra, Ústav ekológie lesa SAV Zvolen, Szlovákia, ISBN 978-80-89408-16-0. 2013. június 18-19.

Tuba, K., **Kelemen, G.** i Varga, M. (2013): Výskyt Rhagoletis completa (Cresson 1929) v Európe /A nyugati dióburok fúrólégy (Rhagoletis completa Cresson 1929) Európában./ (Západomaďarská univ. Šoproň, Maďarsko). In: Hrubík, P. és Gáperová, S. (szerk.) (2013): Dreviny vo verejnej zeleni. Zborník z konferencie s medzinárodnou účasťou. Nyitra, Ústav ekológie lesa SAV Zvolen, Szlovákia, ISBN 978-80-89408-16-0 2013. június 18-19.

Vétek, G., Boros, N., Papp, V., Haltrich, A., Csóka, G., Szőcs, L., Tuba, K., Molnár, M., **Kelemen, G.** és Lakatos, F. (2014): A selyemfényű puszpángmoly (Cydalima perspectalis) 2013-ban ismert elterjedése Magyarországon. Előadás. XXIV. Keszthelyi Növényvédelmi Fórum, Keszthely.

Kelemen, G. (2011): Vergleich mehrerer Baumbewertungsmethoden die die Infrastrukturleistungen der Bäume berücksichtigen. In: Stark, M. (2011): Tagungsband des 43. Forstökonomischen Kolloquiums, Sopron, NymE EMK EVGI. ISBN 978-963-334-022-6., pp. 43-53. 2011. szept. 28-okt. 01.

Kelemen, G. (2010): Tree risk assessments in three dimension. In: Ristić, R. et al. (Szerk.) (2010): First Serbian Forestry Congress, Belgrade, Univ. of Belgrade, Faculty of Forestry. ISBN 978-86-7299-066-9. 88. p. 2010. nov. 11-13.

Tuba, K.- **Kelemen, G.** (2010): Trapping possibilities and results of dusky clearwing. In: Ristić, R. et al. (Szerk.) (2010): First Serbian Forestry Congress, Belgrade, Univ. of Belgrade, Faculty of Forestry. ISBN 978-86-7299-066-9. 163. p. 2010. nov. 11-13.

Kelemen, G. (2005): Az erdőgazdálkodás aktuális kérdései. In: Gömöri, J. (Szerk.) (2005): Az erdő és fa régészete és néprajza Konferencia Kiadvány, Erdészeti, Faipari és Földméréstörténeti Gyűjtemény, Sopron. Tudományos Konferencia, Sopron, NYME EMK Erdészeti Múzeum 2005. máj. 9.

8.3. Scientific presentations

Kelemen, G. és Tuba, K. (2014): Városi fák statikai kérdései. Presentation. Magyar Faápolók II. Konferenciája, Budapest. Magyar Faápolók Egyesülete-BCE Kertészettudományi Kar, 2014. ápr. 25-26.

Kelemen, G. (2009): Átalakító, szálaló üzemmód támogatása. Presentation. „Tarvágásból szálalásba” Konferencia, Sárvár-Hidegkút, Szabó Vendel és NYME EMK EVGI. 2009. nov. 4-5.

Kelemen, G. (2009): Bemutató élő fán a hangtomográf működéséről. Magyar Faápolók Egyesülete Szakmai Nap, Sopron, NymE Botanikus Kert, 2009. okt. 8.

Kelemen, G. (2008): Forstwirtschaft in West-Transdanubien. Presentation. Pannon Napok Nemzetközi Erdész Találkozó, Sárvár-Hidegkút. Országos Erdészeti Egyesület és Szombathelyi Erdészeti Zrt. 2008. máj. 5.

Kelemen, G. (2008): Az energiaültetvények és az MGSZH Erdészeti Igazgatósága. Presentation. „Az energetikai faültetvények erdővédelmi vonatkozásai” Szakmai rendezvény, Sárvár, Erdészeti Tudományos Intézet és az OEE Erdővédelmi Szakosztálya. 2008. aug. 12.

Kelemen, G. (2008): Támogatások és az MGSZH Erdészeti Igazgatósága. Presentation. „Szálalás, átalakítási törekvések az Őrségben és a Vendvidéken” Konferencia, Kétvölgy-Ivánc-Őriszentpéter, Mesics Ferenc, NYME EMK EVGI és Szombathelyi Erdészeti Zrt. 2008. dec. 3-5.

8.4. Posters (in conference proceedings)

Kelemen, G., Tuba, K. és Andrési, D. (2013): Registračný list o’strome (Západomaďarská univerzita, Šoproň, Maďarsko). /Fakataszter/ Nyitra, Szlovákia, Slovenská akadémia vied Ústav ekológie lesa, Pobočka Biológie drevín (Szlovák Tudományos Akadémia Erdők Ökológiája Intézet Fák Biológiája Oszály), ISBN 978-80-89408-16-0 2013. június 18-19.

Tuba, K., **Kelemen, G.** és Varga, A. (2013): Výskyt škodcu *Cydalima perspectalis* WALKER, 1859 na krušpánoch (*Buxus* sp.) v Maďarsku: prvé údaje (Západomaďarská univerzita, Šoproň, Maďarsko). (A selyemfényű puszpángmoly a buxuson, Magyarországon.. Nyitra, Szlovákia. Slovenská akadémia vied Ústav ekológie lesa, Pobočka Biológie drevín (Szlovák Tudományos Akadémia Erdők Ökológiája Intézet Fák Biológiája Oszály), ISBN 978-80-89408-16-0 2013. június 18-19.

Kelemen, G. (2010): Instrumental tree examinations – unusual experiences. In: Findeis, G. et al. (szerk.) (2010): Urban people meet urban forests. Institute of Landscape Development. BOKU University of Landscape, Vienna /Bécs/, Ausztria, p. 49. Tulln, European Forum on Urban Forestry, 2010. máj. 25-29.

Kelemen, G. (2010): Instrumental tree examinations – limits. „Dreviny vo verejnej zeleni 2010” (A fák a közterületeken 2010), Banská Bystrica /Besztercebánya/, Szlovákia. Slovenská akadémia vied Ústav ekológie lesa, Pobočka Biológie drevín (Szlovák Tudományos Akadémia Erdészeti és Ökológiai Intézet Fák Biológiája Oszály) 2010. jún. 22-23.

Kelemen, G. (2009): Műszeres favizsgálatok – tapasztalatok. In: Lakatos, F. és Kui, B. (Szerk.) (2009): Nyugat-magyarországi Egyetem Erdőmérnöki Kar: Kari Tudományos Konferencia Kiadvány, NymE Kiadó, Sopron, 63-66. pp.

8.5. Book chapters

Kelemen, G. (2013): Erdészeti támogatások. pp. 246-261. In: Pápai, G. (szerk.) (2013): Erdőgazdálkodás. Kézikönyv erdőtulajdonosoknak. Mezőgazda Kiadó, Budapest, p. 359. ISBN 978-963-286-702-1 (1-2. kiadás)

Kelemen, G. (2010): Szálaló és átalakító üzemmódú erdők kezelésének támogatása. pp. 138-147. In: Lett, B. et al. (Szerk.) (2010): Múlt és jövő II. „Tarvágásból szálalásba”. Kiadó: Szabó Vendel Egyéni Vállalkozó, Sopron-Mórichida-Szombathely. ISBN 978-963-06-9392-9.

Kelemen, G. (2009): Támogatások. pp. 146-151. In: Lett, B. et al. (Szerk.) (2009): Múlt és jövő. Kisparaszti szálalás a Vendvidéken. Soproni Felsőoktatási Alapítvány, Sopron. ISBN 978-963-06-7086-9

9. SCIENTIFIC PUBLIC ACTIVITIES AND CONFERENCE ORGANIZATIONAL ACTIVITIES

9.1. Conference organizations

-3-5. 12. 2008: „Szálalás, átalakítási törekvések az Őrségben és a Vendvidéken” conference organization, Kétvölgy-Őriszentpéter,

Co-organisers: Mesics Ferenc magán-erdész
NYME Erdőmérnöki Kar EVGI
Szombathelyi Erdészeti Zrt.
Vas Megyei MGSZH Erdészeti Igazgatósága

-4-5. 11. 2009: „Tarvágásból szálalásba” conference organization, Sárvár-Hidegkút,

Co-organisers: Szabó Vendel magán-erdész
NYME Erdőmérnöki Kar EVGI
Vas Megyei MGSZH Erdészeti Igazgatósága

9.2. Memberships

- Magyar Faápolók Egyesülete	membership	since 2009
- Magyar Mérnöki Kamara	membership	since 2009
- Igazságügyi Szakértői Kamara	membership	since 2001
- Kerekerdő Alapítvány	membership	since 1997
- Soproni Erdészdiákok Baráti Köre	membership	since 1985
- Országos Erdészeti Egyesület	membership	since 1984

9.3. Forensic reports

A total of 1,200 forensic expert’s reports, including tree-mechanical expertises, as well as 67 value-damage assessments in various parts of the forestry profession.