PhD Theses

The Reliability and Applications of Dynamic Tree Stability Inspection

Shadabeh Fathi

University of Sopron

Simony Karoly Faculty of Engineering, Wood Science and Applied Arts

The Cziraki Jozsef Doctoral School of Wood Science and Technologies

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Simonyi Karoly Faculty of Engineering, Wood Sience and Applied Arts

The Cziraki József Doctoral School of Wood Science and Technologies

Supervisors: Prof. Dr. László Bejó and Prof. Dr. Ferenc Divós

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Introduction

The stability of trees is an important issue both in the forest and in an urban environment. Research usually focuses on the statistical evaluation of the windfall damage caused by different levels of high wind (e.g. Moore and Maguire 2005; Peltola 2006)

Urban and forest trees pose various risks that may result in considerable damage to public and private property, and also in personal injury, or, in extreme cases, death. The accurate assessment of tree stability and safety is therefore crucial in preventing these highly undesirable outcomes.

Visual tree inspection may be subjective and requires special expertise, much anatomical knowledge and practical experience. Advancement in nondestructive testing (NDT) led to the development of a number of more reliable techniques and instruments in the past 75 years. Various methods and techniques have been advanced during these years, and various manufacturers offer equipment for tree condition and safety assessment.

An approach emerged recently for assessing tree stability and trunk safety. Instead of static loading, this technique uses actual wind loads. This is a more realistic loading scenario, but the interaction of the wind loads and the movement of the various part of the tree is a highly complex process, governed by many variables. While its deterministic modelling is not possible, a statistical approach allows meaningful conclusions based on analysing wind velocity and inclination or trunk deformation.

The dynamic method allows testing several trees at once with ease. It is a useful tool to examine several trees in various conditions to extend our knowledge base about the behavior of trees in different circumstances, and examine the effect of factors such as wind direction, precipitation, temperature, pruning, etc. This was the primary goal of the doctoral research project outlined in this dissertation, along with collecting further data about the applicability and reliability of the new technique.

The aims of the research

The main goals of the doctoral research described in this dissertation were, as follows

- The verification of the applicability and reliability of the dynamic testing technique for tree stability assessment by comparing its results to static testing and uprooting test results.
- Assessing how dynamic tree stability is affected by various factors, including:
  - ✓ soil moisture content,
  - ✓ wind direction, and
  - ✓ seasonal foliage changes.
- Assessing the effect of anthropogenic influences on the stability of trees, through examining the effect of root damages and pruning.

Equipment and Methods

Equipment:

Two different pieces of equipment were used in the project.

- The DynaRoot system is completely non-destructive method, based on measuring wind velocity and tree collar inclination. Grouping the results into batches allows the calculation of statistical parameters of these parameters. The correlation of these statistical parameters can be used to assess the stability of the trees against uprooting. Measurement requires a minimum wind velocity of 25 km/h.

- In the pulling test, horizontal wind load is simulated by static loads, exerted via a cable affixed to the tree trunk, while measuring the inclination at the base of the trunk. The induced inclination is slight (less than 0.2 degrees), to make sure that the test does not damage or start uprooting the tree. The data is recorded and analysed in real time to create a load-inclination curve and assess the safety of the tree. Successful measurement requires low wind velocities below 25 km/h.

Both methods allows the creation of load-inclination curves based on the measured data. Extrapolation of the curves yields an ultimate load value, from which the uprooting torque or uprooting wind pressure may be determined. Based on high wind velocity, we can calculate the maximum torque or wind pressure that the tree may experience. Comparing these two values. we may calculate the so-called Safety Factor (SF) value. SF values below 1 and above 1.5 indicate that the tree is unsafe or safe, respectively. If the SF is between 1 and 1.5, tree safety is uncertain, and the tree should be monitored for safety.

The measurements were carried out and analysed using the instruments and software of the FAKOPP enterprise, including Dynaroot, Pulling test and the ArborSonic 3D software to determine the geometric parameters of the crown.

Experimental methods

Three different studies were set up to verify the applicability of dynamic testing for tree stability assessment, and to study the effect of natural and anthropogenic factors on the stability of trees.

- In the first part of this research, 10 decayed ash trees were chosen in a forest in Donaudorf, Austria. The stability of the trees was evaluated both by the pulling test, and using the DynaRoot system. DynaRoot measurements were taken on the same day after the static and dynamic measurements, all ten trees were tested all the way to uprooting to determine the uprooting torque.
- In second part, tree stability was measured on several tree specimens in the Botanical Gardens of the University of Sopron. Several conifers and broadleaved trees were chosen and tested in different seasons and under different conditions. Unfortunately, measurement conditions could not be controlled, which makes the evaluation of the results somewhat complicated. Nevertheless, we made an effort to build a considerable database. This allowed us to assess the effect of changing the foliage, weather, temperature and other seasonal variation in various trees. The crown surface and crown center height values were calculated using the ArborSonic 3D software, based on photographs taken of each tree at the time of the dynamic measurement, based on laser-assisted height measurements. The anemometer also collects wind direction information, which yielded the average wind direction used in our analysis. Finally, soil moisture content was also measured by taking a soil sample at the time of measurement near the measured

trees, at a depth of approx. 25 cm. Moisture content was determined by drying the soil sample.

- In the third phase of this research, 2 pine trees close to one another were chosen in University Botanical Gardens. First, the original stability of the trees was measured using DynaRoot at two different times, before modification. After the initial assessment of the dynamic safety factor, the root system of Pine tree nr. 1 was examined by acoustic root mapping, and a number of roots were severed. In the case of Pine nr. 2, the crown was reduced by approx. 50%. After these modifications, the stability of the tree was, again measured twice using the DynaRoot system.

Result and Discussion

Comparing the results of dynamic and static stability assessment:

Critical moment and SF was predicted from the pulling test, and also calculated from the dynamic testing results, to facilitate comparison with the pulling test and actual uprooting torque. Comparison of the static pulling, dynaroot and actual uprooting torque determination yielded the following results:

- the pulling test estimates the uprooting moment with a very high level of accuracy. The relationship between the pulling test SF and actual uprooting torque was very strong (r^2 = 0.71) which is a good indication that the pulling test Safety Factor is a reliable parameter for predicting the stability of trees.

- The dynamic SF predicted the ultimate uprooting moment even better than the static value, with an r^2 value of 0.86. This is somewhat surprising, since the dynamically measured parameters were expected to perform poorer when predicting the static uprooting torque. In any case, the good correlation is an encouraging sign concerning the reliability of the dynamic method.
- The relationship between the static and dynamic Safety Factor is not very strong, but the r^2 value is still above 0.5, which is acceptable in biological materials. The relatively week relationship shows that the two different Safety Factor values are not completely interchangeable, as one measures tree behavior in a static loading scenario, while the other describes its dynamic response. Nevertheless, both are closely related to the uprooting moment, and both may be recommended for assessing tree stability. This confirms the preliminary findings outlined in Divos et al. 2015 and Bejo et al. 2017.

The effect of seasonal and weather conditions

A total of 73 measurements were taken on 18 trees in different weather and seasonal conditions. Since there was no way to control measurement conditions, these measurements include a wide variety of soil moisture content, wind velocity and direction, as well as diverse foliage conditions in the case of broadleaved trees. The measurement included 9 conifers and 9 broadleaved trees.

Tree-by-tree analysis of the results delivers no clear trends. This apparent lack of relationship is mostly because of the relatively small number of measurements in each tree. Combining the results of the individual trees may highlight trends and tendencies not evident in tree-by-tree analysis.

To facilitate comparison, the relative Safety Factor, moisture content, and crown surface was calculated instead, by comparing the measured values to the average of each tree, expressed as a percentage of the average. Thus, the relative change in these parameters, rather than their absolute values, was considered. Wind direction was not normalized, but instead calculated as the deviation from the prevalent wind direction (NW, or 315°) in degrees.

Experimental results revealed the following relationships between the examined factors and tree stability:

- Soil moisture content had a strong positive correlation with the dynamic Safety Factor of coniferous trees. This somewhat surprising result is most likely due to the root structure of these trees. Many coniferous trees (like pines and fir) have a taproot system, with the main root reaching deep into the ground. The compaction of the lower soil layers by the added weight of the topsoil may stabilize deep-reaching roots. Other trees (like sequoia) have a dense, matted root system, which incorporates large amounts of soil. The added weight of this soil helps anchoring the tree and, again, improves stability (Fathi et al. 2020).
- There was no strong correlation between soil moisture content and the SF of broadleaved trees. Other factors, like seasonal foliage changes or gross anatomical differences, particularly those of the root system, probably have a more important effect on the stability of broadleaved trees.

- Wind direction variation had less of an effect on the stability of broadleaved and coniferous trees than expected. This was partly due to the shortage of crosswind measurements, and partly because other factors may be more influential on dynamic stability. This is an advantage from a practical application point-of-view, where arborists and other experts do not have to worry about the effect of wind direction variations.
- Seasonal foliage loss had a weak positive effect on the stability of broadleaved trees. When trees lose their leaves, there is less crown area for the winds to act upon, which improves stability, but, in the meantime, the drag factor also increases, which also influences the results; this is why the correlation is relatively weak. Recent results reported by some German researchers show increased movement of broadleaved trees in the winter, when the leaves are missing. (Göcke et al. 2018.)

The effect of anthropogenic interference on the stability of conifers

Results shows that artificial root damage did not cause significant changes in the Safety Factor of the examined pine tree. The average Safety Factor was close to 1.6 both before and after the intervention. This was not unexpected, since the root damage was relatively small, and affected the superficial roots only. Since pines, like many other coniferous trees, have a taproot system (Wessolly and Erb 2016), even cutting most of the superficial roots may not have a significant effect on their stability. More extensive studies, cutting more of the superficial roots, and possibly conducted on trees with a more fibrous root system could shed more light on the effect of root damage.

As opposed to root damage, the pruning of the crown evidently caused serious improvement in the stability of Pine nr. 2. On average, the SF value increased by more than 50%, due to an estimated reduction of 50% of the crown surface area. This shows that pruning is an effective tool for improving the stability of urban trees. These results may seem to be in contrast to the relatively weak effect of seasonal foliage change in broadleaved species. However, in those cases the branches were not removed, only the foliage changed. When trees are pruned, the branches are also removed, so the drag factor is not significantly affected, only the crown surface changes. While the results concerning the effects of pruning are encouraging, more measurements, including the removal of branches in several stages, and involving more trees and several species are recommended for a more in-depth analysis of the relationship between pruning and tree stability. Our current results are, at best, preliminary, but will hopefully inspire further research in this area.

Scientific statements

Based on the results and conclusions of my project, I have formulated the following scientific statements:

- I have confirmed that dynamic tree stability assessment is a valid tool for assessing the stability and safety of urban and forest trees. Because of the dynamic loading scenario it is likely to be as good or better than the pulling test for this purpose.
- I have shown that soil moisture content is an important natural factor that influences tree stability in coniferous trees.
- I have concluded that, while foliage loss has some positive effect on the safety factor of broadleaved trees, their stability is determined by a number of factors in a complex interaction. This phenomenon needs to be further investigated to gain a better understanding of the stability of deciduous trees.
- I have concluded that, contrary to expectation, wind direction does not significantly influence the dynamic Safety Factor of trees. Other factors are more influential in determining their stability.
- I have proved experimentally that pruning is an effective tool to improve the safety of urban trees, due to the significant improvement in the dynamic safety factor.

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