Wind Tipping Curves – Assessing the Anchorage and Wind Load of Urban Trees by Motion Monitoring

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Abstract

To date, the anchorage and wind load of urban trees can only be assessed in static load tests. These are complex and expensive, and the reliability of wind load estimates has been questioned. Monitoring the basal inclination of trees in natural winds yields a wind tipping curve, which can be used to inexpensively assess anchorage. Combining this with static load test allows to estimate real wind loads, which can be used to assess the conventionally used wind load estimates. Our analyses show that wind speed data can be taken from weather stations several kilometers away from the tree. The quality of the wind speed-tilt correlation does vary, depending on local conditions and topography.The differences between measured and estimated wind loads were rather modest between 4 % and 31 %. Thus, our results show that dynamic loads in gusts are comparable to the results of a wind load analysis. They cause a maximum reaction that can be reproduced in static load tests.

Keywords: tree risk assessment, anchorage, root plate inclination, wind, static load tests

Introduction

In many parts of the world, there is a legal obligation to assess the risk posed by urban and roadside trees (Smiley *et al.* 2012, Rust 2016). Frequently, failure is initiated by damages to the root system compromising the anchorage of trees. Consequently, there is a need for cost-effective ways to assess the anchorage strength of large numbers of trees.

Wind is the major load on trees and a principal cause of their failure (Metzger 1893, Jacobs 1936, Mergen 1952). The wind load in the crown causes a turning moment at the base of the tree that inclines the stem base. This stem base inclination is a function of the turning moment and the stiffness of the root-soil system (Coutts 1983, Lundström *et al.* 2007).

The initial stiffness of the root-soil system correlates with the anchorage strength of a tree (Neild and Wood 1999, Jonsson *et al.* 2006, Detter and Rust 2013). Results from static pulling tests on several European and North American tree species show a close correlation of the bending moment required to tilt a tree to 0.25° and the bending moment at failure (Detter and Rust 2013).

Thus, measurements of the rotational angle of the root plate in winds can be used to assess the anchorage strength of trees (James *et al.* 2013). Until recently, however, the tilt data have been evaluated without using wind data quantitatively and depended on wind measurements as close to the tree as possible. Yet, in many urban sites, where a tree is to be assessed, it will be difficult or even impossible to install a 10 m pole for wind measurements correctly.

The average wind speed may be far below the gust wind speed. Thus, the randomly occurring gusts pose the main load to the trees. Their size and direction vary and measuring the wind a specific tree is exposed to is expensive and technically complex. Recently, we proposed to use the correlation between peak root plate inclination per time-slot and the peak wind gust speed in the same time slot, using official regional data and thus avoiding the need for specifically setting-up instruments close to the trees (Göcke et al. 2018). Extending this approach, we combined those experiments with static load tests to evaluate the accuracy of wind load estimates, which are a crucial part of tree assessment (Esche et al. 2018).

Material and Methods

Trees and Sites

Mature trees of several species, including Acer pseudoplatanus, Fagus sylvatica, Quercus robur, and Populus sp. were measured at several sites in Germany.

Inclination in natural Wind

Trees were equipped with tilt sensor (TMS2 and TMS3, argus electronic, Rostock, Germany) at their base prior to wind events. Wind speed data were provided by the German National Weather Service. We used the weather stations closest to the tree sites. Distance were in the range of 5 to 19 km. Maximum average wind speed in 1 h windows was scaled by a gust factor to give maximum gust wind speed. Maximum root plate inclination in 1 h windows was plotted against these wind speeds to produce wind tipping curves (Göcke et al. 2018).

Static Load Tests

Static load tests as proposed by Wessolly (1998) were used to establish the relationship between load and root plate inclination. We used TreeQinetic-devices (argus electronic, Rostock, Germany).

Wind Load Estimates

Wind load was estimated using Arbostat software (Arbosafe, Gauting Germany). Input data were crown size and shape, tree height, tree diameter, and parameters describing local wind and its interaction with the tree. The resulting estimate is a bending moment at the stem base at a given design wind speed (Esche et al. 2018).

Results and discussion

Wind Tipping Curves

With few exceptions, there was a close correlation between root plate inclination and wind speed. We demonstrate results using the example of a row of mature *Fagus sylvatica* close to Göttingen, Germany (Figure 1). While the root plate of seven trees did not move very much, two trees reacted strongly to the wind. One of them is infected by *Meripilus gigantaeus*, the other one split open at its base during the storm.

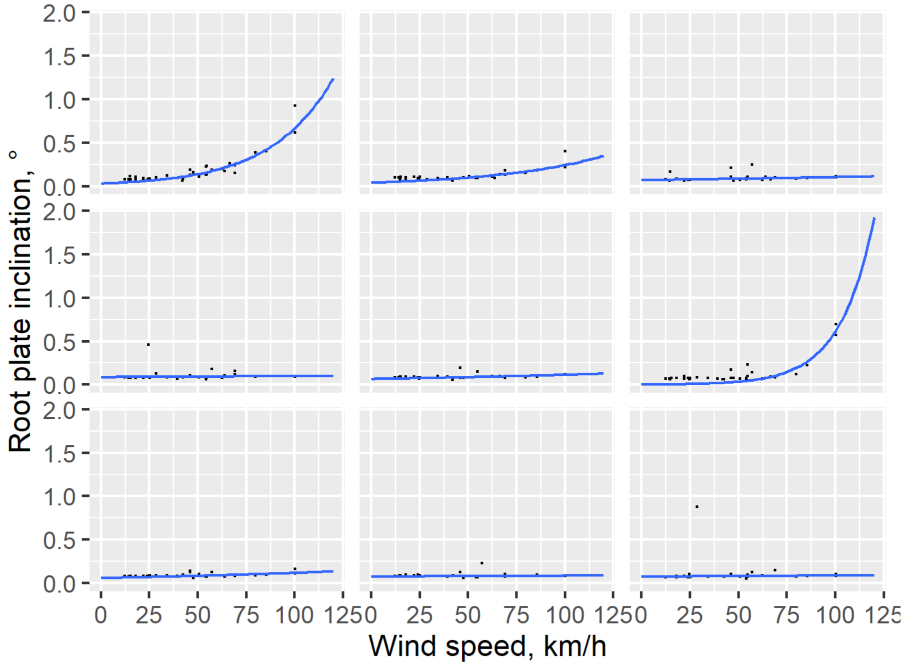

Figure 1- Wind tipping curves of a row of mature *Fagus sylvatica*.

Wind tipping curves can thus be an inexpensive method to identify hazardous trees. A major limitation is, that high wind speeds are required, which may not occur during the time a consultant has to assess a tree. Additionally, complex terrain might prohibit using weather stations several kilometers away.

Verification of wind load estimates

Wind load estimated using the wind load analyses of the software Arbostat agrees suprisingly well with wind load measured using wind tipping curves and static load tests. We demonstrate this with a set of four trees measured in Northwest Germany (Figure 2). Deviations between the results of the two methods were rather small.

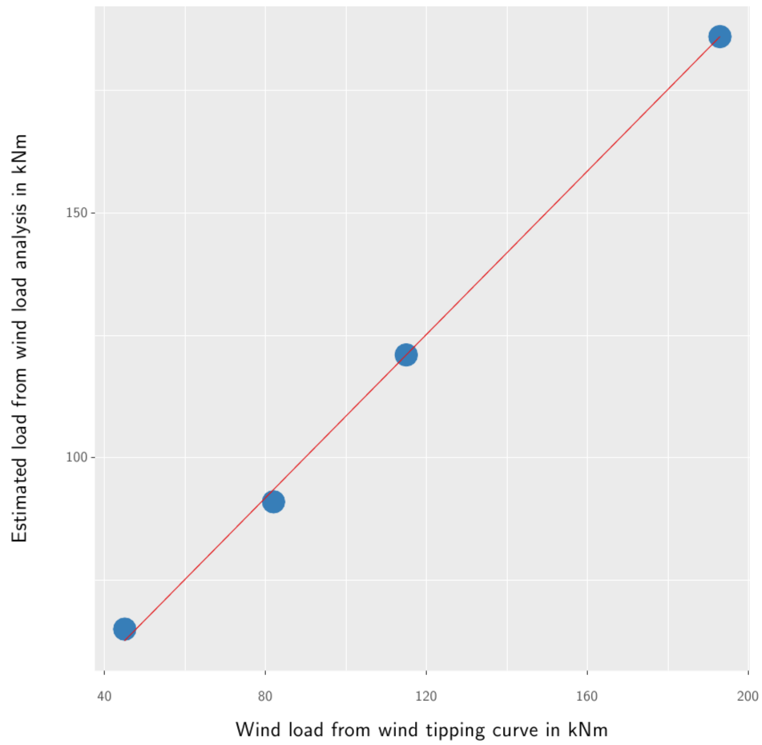

Figure 2. Wind load estimates using tree movement in natural wind and static load tests compared those generated by the software Arbostat.

Conclusions

Concurrent measurements of root plate inclination and wind speed – wind tipping curves – can be a valuable extension of static load tests. They can be used to identify potentially hazarduos trees alone, or in combination with load tests. Furthermore, they can support the sometimes questioned wind load analyses, which are an integral part of the method.

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