How much crown pruning is needed for a specific wind-load reduction?

Frank Rinn

Abstract: Crown reduction is a standard procedure to reduce the risk of urban trees with structural defects near the trunk base. However, the recommended amount of pruning is usually based on a ‘gut-feeling’. Understanding principles of tree wind-load as presented here will enable tree experts to more accurately determine how much of the crown to remove. In general, trees need to be pruned (their crowns reduced) much less than many arborists think to compensate for risk due to trunk or root defects. The advantages of less pruning and fewer and smaller pruning cuts include reduced impact on tree health and appearance, and environmental benefits, less pruning response, and cost-savings to the tree owner.

Keywords: wind load, crown reduction, pruning, and tree safety

Introduction

When significant trunk and root collar defects are identified in urban trees, crown reduction is one of the most common practices to reduce wind load and, as a consequence, to increase the so-called breaking and uprooting safety. Although this is a standard procedure in many countries, the amount of required reduction is mostly estimated by ‘gut-feeling’. Many arborists use the percentage of trunk cross-sectional area loss determined or estimated at the trunk defect as a guide to the amount of height or crown sail area reduction needed to achieve reasonable safety. For example: if 50 percent of the trunk cross-section is decayed, the crown has to be reduced by 50 percent. In general, this is far more than actually needed.

The impact of a specific amount of height or wind-sail area reduction cannot be directly translated into a corresponding wind-load reduction because the functional dependencies are complex and not linear. To make decisions on crown reduction pruning more precise and reliable, a basic understanding of tree wind-load, as described below, is mandatory.

In this simplified approach, torsional aspects are left out, as they are much more complex and shall be described in another article. Thus, this text focuses on the bending moments at the stem base due to wind-loading.

Tree wind-load relations

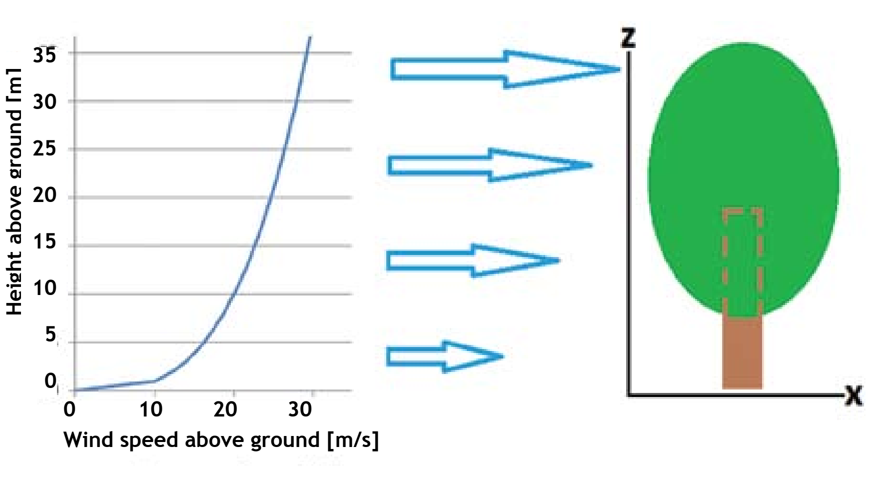
The discussion presented below regarding wind-load basics is a summary of concepts excerpted from published articles by Davenport, Ruck, Spatz, Brüchert, and Niklas. Following Davenport (**Fig. 1**), wind speed (v) increases with height above ground (z) and this is typically described by the following equation:

$$v(z) = v\left(z_{ref}\right) * \frac{z^a}{z_{ref}^a}$$

z_{ref} is defined as the height above ground where the wind is no longer disturbed by surface roughness, such

Tree height is the most important factor dominating trunk base bending-moment due to wind-loading of mature urban trees.

Figure 1. Assuming a ‘roughness’ parameter for typical suburban situations (a~0.3) and a wind speed of 40m/s on 100m above ground (=reference height), this is the resulting vertical increase of wind speed dragging the tree crown.



as trees or buildings. The exponent (a) describes the surface roughness and typically ranges from 0.1 to 0.5:

Surface type	Exponent
Town center	0.4
Suburbs	0.3
Forests	0.28
Agricultural land	0.25
Ocean	0.16

For the typical urban and suburban tree to be inspected in terms of traffic safety, the exponent (a) thus ranges between 0.3 and 0.4.

The drag on any part (i) of the crown 'sail area' as represented by the locally acting force (f_i) mainly depends on wind speed (v), air density (q) and the drag coefficient (c):

$$f_i \sim \tfrac{1}{2} * q * c * v^2$$

In a simplified approach, the total force (F) on a tree crown with a 'sail' area (A) is a sum of all (infinitesimal) forces (f_i):

$$F = \sum f_i = \tfrac{1}{2} * q * c * v^2 * A$$

This approach is a very rough approximation for several reasons, such as:

- Wind speed (v) changes with height above ground.
- The drag coefficient (c) of the crown changes with wind speed (v).
- The 'sail' area (A) changes with wind speed (v).

The dependencies, especially between wind-speed, height, drag coefficient, and sail area, are nonlinear, and thus difficult to describe here comprehensively. However, a simple approach can be applied based on measurements published by Ruck that showed how the drag coefficient of trees drops from around 1 for low wind speeds to approximately 0.3 for high wind speeds in storms and gusts (>30m/s). This drop in drag-coefficient covers the effects of both crown re-configuration and smaller sail area in higher wind speeds.

Assuming constant air density and drag coefficient, the total force (F) acting on a tree crown is proportional to a wind speed integral over the surface area:

$$F \sim \iint \left(v(z)\right)^2 \, dx \, dz$$

Effective wind load

In terms of engineering, safety of a structure is mostly defined as the load-carrying capacity divided by the load. This value is often called the "safety factor". Consequently, stem breakage and uprooting safety of a tree are usually determined by the corresponding load-carrying capacity divided by the bending or tipping moment as representing the load. For calculating the bending moment, the force (f_i) acting on each part (i) of the crown sail area (A) has to be multiplied by the length of the acting lever arm (l_i), which, in this simplified case, is height (z) above ground:

$$m_i = f_i * l_i = f_i * z_i$$

The total bending moment (M) acting at the stem base is proportional to wind speed multiplied by height, integrated over the crown surface area:

$$M \sim \iint \left(v(z)\right)^2 * z \, dx \, dz$$

Replacing wind speed by its determining parameters, the total wind bending moment (representing the load on the tree) can be described by:

$$M \sim \frac{v\left(z_{ref}\right)^2}{z_{ref}^{2a}} \iint z^{1+2a} \, dx \, dz$$

The integral represents a sum of infinitesimal steps, running over the sail area (x from 0 to crown width W, and z from 0 at ground level to tree height H). Despite the importance of shape of the crown sail-area, the integration result reflects the dominating influence of tree height and crown width on bending moment as the major functional dependencies:

$$M \sim W * H^{2+2a}$$

Hasenauer showed in empirical studies (1997) that the crown diameter of solitary trees typically correlates with tree height: crown-width ~ tree-height^b, b>1, resulting in:

$$M \sim H^{2+2a+b}$$

Assuming the height exponent (a) is being approximately 0.3 to 0.4 for urban and suburban trees, the bending moment at trunk base depends on tree height to the power of more than 3.5:

$$M \sim H^{3.5+\dots}$$

That means that tree height is the most important factor dominating trunk base bending-moment due to wind-loading of mature urban trees.

Practical consequences

If two trees of similar crown architecture and site conditions are compared and one has a height twice that of the other, the wind-load bending moment at the stem base of the taller tree would be at least an eight times higher ($2^3=8$) than that of the shorter tree. However, due to the influence of width, shape, and height of the crown, a tree-height reduction of 10% (H*0.9) does not directly lead to a wind-load reduction of 27 percent ($0.9^3 \approx 0.73$) or 31% ($0.9^{3.5} \approx 0.69$). But, the resulting wind-load reduction percentage is commonly significantly greater than the reduction of the tree height and crown sail area.

If we assume, in a simplified approach, a tree resembling a circle on a pole (**Fig. 2**), the resulting wind-load reduction can be approximately twice as high as the reduction in height. That means, in this case, if tree height is reduced by 10 percent, wind-load is reduced by 20%, approximately.

In a more typical case of a common mature urban tree (**Fig. 3**), resulting wind-load reduction is more than twice the reduction in tree height. Although this amplification factor of 2 or more is very common, there is no

Figure 2. (Left) If this nearly circularly shaped crown would be reduced in height by about 10% this would lead to a reduction of the sail area by a little more than 10% and of the wind load by about 20%, approximately.

Figure 3. (Right) A reduction of the tree height by about 20%, in this case, leads to a reduction of the sail area by about 30% and squeezes down the wind load bending moment at the stem base by about approximately 50%.

simple rule for calculating the resulting wind-load reduction from the amount of height reduction because it depends on the ratio of crown height and width to overall tree height. As a rule of thumb, a factor of two is reasonable. That means, if a tree needs a strong reduction of wind load by about 50% (because of decay in the trunk base, or increased wind-load due to site changes), tree height has to be reduced most likely by less than 25 percent!

In addition, we have to take into account that the size of internal decay column does not equal the corresponding loss in load-carrying capacity (Rinn 2011) and that mature trees inherit much higher safety factors due to their natural allometric design (Rinn 2013).This commonly results in much lesser required wind-load reduction even when extensive defects are present as compared to many currently applied standard procedures.

If all these aspects are understood and applied in combination, the actual level of crown reduction required will often be much less than commonly practiced. Mature trees will remain healthier and survive longer when their crowns are reduced to the extent actually needed to achieve reasonable tree safety. In addition, less crown reduction leaves greater photosynthetic capacity, enabling trees to better defend themselves against insect pests, and fungal pathogens. Thus, when properly applied, crown reduction improves tree safety and, at the same time, has significantly less negative impacts on tree health and vitality, as well as esthetic and environmental benefits, while providing cost-saving to private and municipal tree owners. It also can minimize the chance of sunburn injury and resultant decay, particularly in species sensitive to extensive pruning.

Frank Rinn
Heidelberg/Germany

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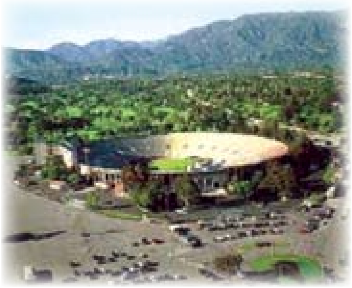

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