Tree of Knowledge

The One Third Rule

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Shortly after the first presentations, the so-called "one-third-rule" (see for example: Mattheck et al. 1993) became a popular criterion for evaluating the breaking safety of urban trees around the world: as soon as the thickness of the outer intact shell-wall (t) of a hollow or decayed tree stem is less than 1/3 of the local radius (R), this stem section was supposed to be significantly more likely to break under wind loads. Many arborists, and probably even more judicial and insurance experts around the world, interpreted the corresponding graph (Fig. 1) as defining a clear line between "safe" and "unsafe". As a central part of the so-called VTA concept ("Visual Tree Assessment": Mattheck & Breloer 1994), the t/R>1/3-rule is still the most commonly applied tree-breakage safety threshold around the world.

However, since its introduction, the 1/3 rule has been widely criticized especially from experts preferring the SIA concept for evaluating tree-safety ("Static Integrated Assessment": Wessolly & Erb 1998). Gruber (2007, 2008), for example, criticised the VTA-1/3-rule as a "scientifically unproven", "mono-causal" and "untenable failure criteria" for trees. On the website www.dasgruen.de, several publications and statements from various authors can be downloaded in support of Gruber's criticism against the use of the 1/3 rule and other VTA thresholds, such as the H/D (height/diameter) ratio. In addition, many arborists have observed real trees breaking with small or no defects (Fig. 2), and mature trees standing on thin shell walls for decades (Fig. 3). These observations tend to confirm Gruber's criticism that the 1/3-rule is not correct.

Several other professors from public universities support Gruber's position and promote SIA, while criticising the 1/3-rule in VTA. In consequence, the criticism of the "mono-causal" VTA criteria developed into a mono-culture of SIA advocates dominating nearly all tree-care conferences and educational institutions in tree safety issues. This trend is seen not only in Germany, where the debate started and was successfully exported, but even internationally: at an international tree-biomechanics conference in USA, for example, nine out of ten presentations criticised VTA and promoted SIA and the related diagnostic products of one company.

Mattheck and Bethge responded clearly to the criticism of Gruber and others (2007, 2008) and claimed: VTA and the 1/3-rule are valid results of reliable scientific studies and SIA is based only on assertions. In 2009, Fink (a widely respected forest pathologist) confirmed Mattheck's statements and clearly contradicted Gruber's positions as well.

This debate left many arborists and experts around the world in confusion: the by far the most frequently asked question I am getting at workshops around the world is: "Who is right: VTA or SIA?" in conjunction with "Can we still use the 1/3-rule for safety evaluations although most well-known experts now prefer and promote SIA?" Thus, there seems to be a need for a clarification of this aspect.

Basics

According to Gere & Timoshenko (1997), the relative load carrying capacity (rLCC) of a circular cross-section of a homogeneous material (with outer diameter D), covering a centrally located void (of diameter d) is proportional mainly to these two geometric properties. Consequently, it can be written as a function of radius (R) and shell wall thickness (t) as well:

$$rLCC \sim (D^4 - d^4) / D = 8 (R^4 - (R - t)^4) / R$$

This calculation determines the so-called "section modulus". Using this formula, it can be shown how the normalised bending load-carrying capacity of a cross-section depends on the ratio of t/R (Fig. 4). But, this concept only recognises longitudinal tension and compression stresses and assumes a homogeneous material. Because wood is not homogeneous and not isotropic, the section modulus cannot describe the behavior of cross-sections having large defects: a deeper analysis of these aspects by Ledermann (2003) shows that even when loaded under bending, tangential tension stresses occur in the cross-section (Fig. 5). And these stresses are significantly stronger when t/R decreases as compared to tension and compression stresses (covered by the section modulus as described above)This is important for wood because it is non-homogeneous and non-isotropic (Blass & Schmidt 1998): material strength properties vary significantly depending on loading direction relative to the fibres, and torsional strength is by far the weakest, making wood significantly more susceptible to shear and tangential tension stresses. Consequently, the real load-carrying capacity of hollow wooden cross-sections is significantly smaller compared to homogeneous materials (as shown in Fig 4. and represented by the section modulus) as soon as the ratio of shell wall to radius drops down below approximately 1/4 or 1/5 (Fig. 6) – depending on the longitudinal size of the defect and depending on various wood

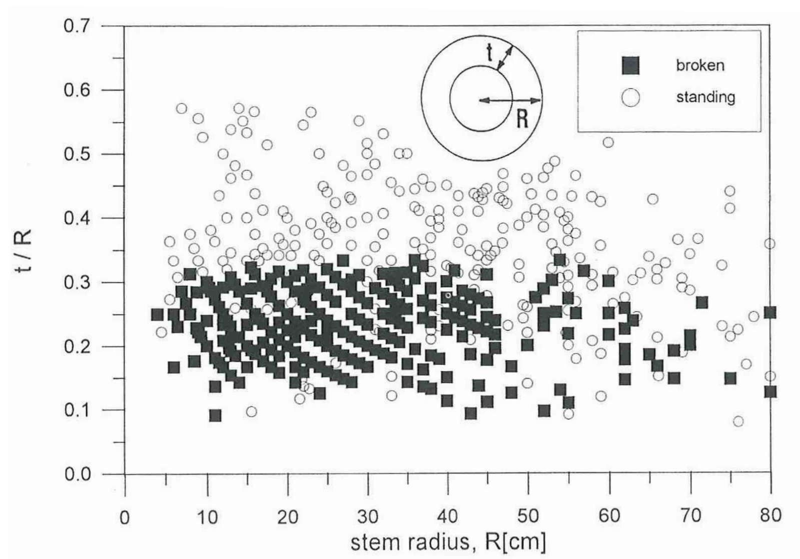


Figure 1

This is one of the graphs that were used to prove the 1/3-rule (Mattheck et al. 1993): broken stems with centrally rotten zones are represented by black squares and hollow circles show standing trees with corresponding central defects. The position of the symbols is defined by the outer radius of the stem (R) on the abscissa (X) and the ration of t/R on the ordinate (Y) axis. The fact that no black squares are shown above t/R=1/3 led to the first interpretation of this graph by many (if not most) arborists: as long as t/R>1/3, the tree is safe and will not break.

Figure 2
Two of many examples of broken conifer trees (Picea abies) not represented in Fig. 1. The tree on the left had a small defect in the center of the stem base with t/R≈1/2 but broke on a height where t/R≈4/5. The tree on the right was fully intact (t/R=1) and broke in a combination of torsional and dynamic loading in a wind gust of a thunderstorm (while the author was standing beside the tree inspecting the stem). Such failures should be represented by at least a few black squares above the 1/3-line in Fig. 1, but, such values are missing.

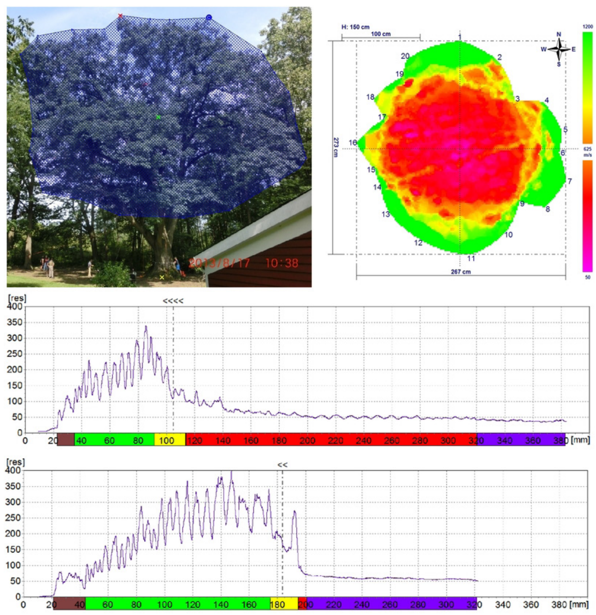


Figure 3
This mature oak tree (Quercus) has a diameter at breast height of more than 2.5m (>100"). As can be seen by the sonic tomograph (Rinn 1999, 2014b) and the resistance drilling profiles (Rinn 1988, 1990, 2016), the intact outer shell wall ranges from a few centimetres to approximately 30cm (12"). The average shell wall thickness is less than 25cm (~10"), which means t/R<1/5. This tree is standing although being heavily defective and hollow for decades and providing a significant total height of more than 25m. Arborists, strictly applying the 1/3-rule as commonly understood, usually condemn such trees as being unsafe or tend to recommend strong pruning and even cabling, although often there is no need for that and although strong reductions significantly contribute to an accelerated spread of internal fungal defects (Rayner & Boddy 1983). Applying the tree-safety concept presented here, leads to different conclusions and mostly results in nothing to be done or pruning the crown symmetrically in order to prevent wind-induced torsional loads.

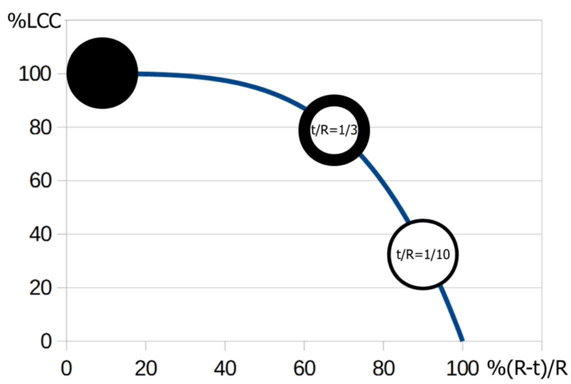


Figure 4
This graph visualises how the relative load-carrying capacity (%LCC) of a cross-section depends on the shell wall thickness and corresponding „hollowness", according to Gere and Timoshenko (1997) for homogeneous materials. The curve starts at left with t=R at 100%, representing the fully wooded and intact cross-section. With decreasing shell wall (t), the size of the centrally located void increases and leads to a correspondingly bigger loss in load-carrying capacity. Surprisingly not only to many arborists, with t/R=1/3, the central void covers approximately 45% of the crosssectional area but leads to a loss in load-carrying capacity of only about ~20%. From this point on, however, with further decreasing shell wall and increasing void size, the loss in load-carrying capacity increases more significantly than before. Because of that, t/R=1/3 is seen by many as a "turning-point" from where to start worrying about stability. But, it is important to understand that this is valid only for trees still growing in height with centrally rotten circular stem cross-sections. For other trees, another concept has to be applied.

material properties (Spatz & Niklas 2013). That means, according to Fig. 6, as soon as t/R drops below approximately 1/3 or 1/4, the load-carrying capacity of the corresponding cross-section decreases significantly as compared to the simplifying section modulus concept (used by SIA, for example, as can be seen in Fig. 12). The findings of Scatter and Kucera (2000) confirm that torsional loading is a frequent cause of failure for trees (Fig 7).

Obviously, nature knows about these aspects of stability in such kinds of structures: radial density profiles of coconut palms, for example, typically show significantly higher density on about 1/3 of the outer part of the radius (Fig 8). Thus, there must be a reason for this kind of internal mechanical design, otherwise, the evolutionary process would not have selected this concept. Interestingly, the ratio of total tree height (H) over diameter at breast height (D) and several other allometric properties of coconut palms are similar to those of slender conifer forest trees (Fig. 9) from which the data for the 1/3-rule graph (Fig. 1) was derived.

This means, t/R~1/3 seems to have a meaning in terms of the load-carrying capacity of hollow or rotten stems of a specific kind of tree (centrally rotten circular stem), but the question is how to apply this knowledge practically to the typical mature urban tree to be inspected in terms of safety?

At the real urban tree

Arborists trying to practically apply the 1/3-rule quickly realise that mature urban trees are much more difficult when compared to the common young slender forest tree with a centrally rotten zone (Fig. 10). The typical urban road-side or park tree to be inspected in terms of safety is different in many ways:

- the cross-section of the trunk at the stem base – root transition is not circular
- the defects are mostly not located in
- the center of the cross-section.

As a result, the 1/3-rule simply cannot be applied because there are hundreds of different t/R values in the same cross-section.

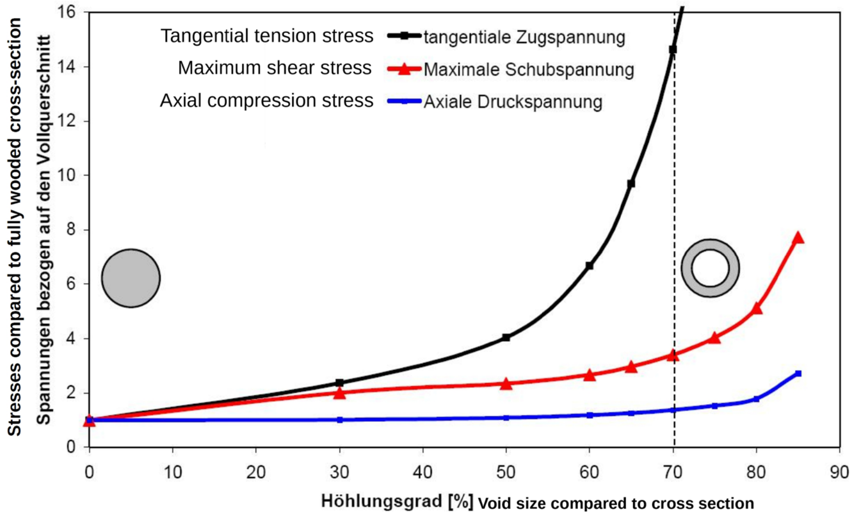


Figure 5

Ledermann (2003) showed that shear (red) and tangential tension (black) stresses increase significantly more strongly compared to longitudinal compression stresses (blue) when hollow cross-sections are loaded under bending – depending on the shell wall thickness. This is important for wood because torsional strength is by far the weakest material property (Blass & Schmidt 1998).

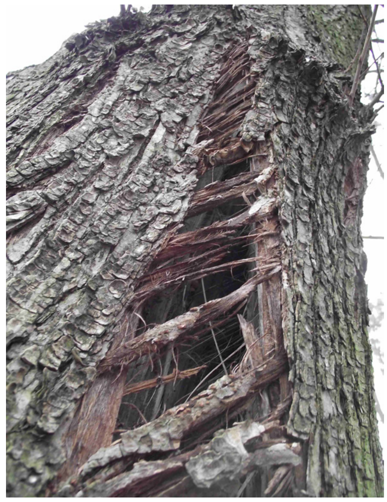


Figure 7

Torsional failure of hollowed trunks like that shown here (Picture by Duncan Slater) are mostly observed at trees with t/R<1/4 (and thus below 1/3 as well).

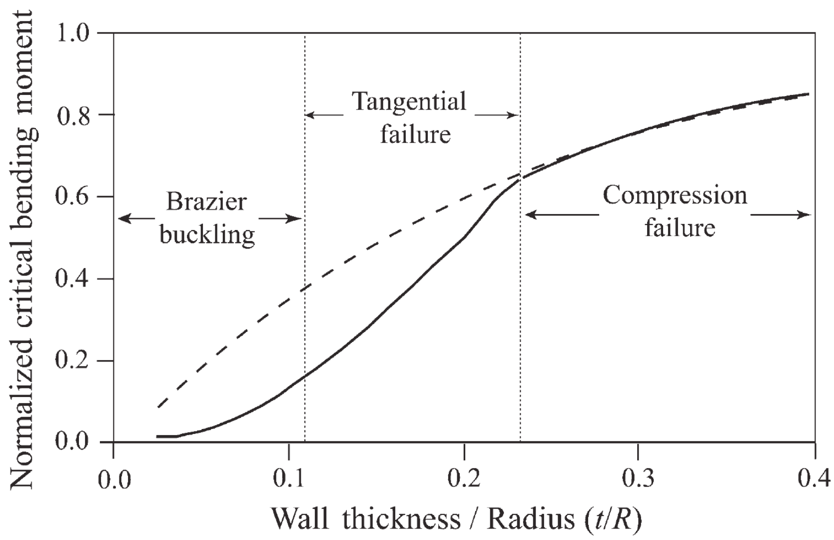


Figure 6

Mainly in consequence of the relatively low torsional strength of wood (Blass & Schmidt 1998) and because bending loads lead to shear and tangential stresses (Ledermann 2003), the real load-carrying capacity (as represented by the critical bending moment and shown here with a solid line) is significantly smaller than the simplifying section modulus concept (dotted line) as soon as t/R<1/4 (Spatz & Niklas 2013). This explains why evaluation methods (like SIA) based only on the section modulus and ignoring shear and torsional stresses overestimate the load-carrying capacity of thin-walled hollow cross-sections (Fig. 12).

Which one is the correct for evaluating safety? None, when taking into account the findings described in the previous section. Does that mean, the 1/3-rule is worthless? Fortunately not!

As shown above, a circular stem with a central void gets significantly more susceptible to breakage as soon as the shell wall drops below t/R=1/3, that is, as soon as the loss in load-carrying capacity due to the defect is higher than 20%. Then, why should natural evolution not provide the same threshold when cross-sections are not circular and defects are not concentric? Thus, it seems very logical that tree stems as natural, mechanically loaded structures in general tolerate up to approximately 20% loss in load-carrying capacity due to defects without getting significantly more susceptible to breakage -- for all kinds of cross-sectional shapes and locations of defects. This threshold we can apply to any kind of cross-sectional shape with any kind and location of defect(s): we just have to determine the loss in load-carrying capacity depending on the size and shape of the cross-section and depending on the location and size of the defect(s).

To do this, we need a tomographic representation of the cross-section. That can be done either by applying sonic tomography (Rinn 1999; 2014b) or by simply drawing the cross-section by hand on a smartphone/tablet application (Fig. 11), based on visual estimation or some resistance drillings (Rinn 1990, 2012, 2016). Although such tomographic approaches may look simple, using such kinds of applications and calculations requires a basic understanding of the topic. And it has to be done carefully.

The smartphone application shown here calculates only geometrical properties of the section modulus and delivers relative results: the relative loss in load-carrying capacity of a defective cross-section in comparison to the fully intact situation. For two reasons, this relative approach does not take into account the potentially differing material properties within the cross-section: on the one hand, it is practically impossible to measure the material properties of a cross-section precisely enough without destroying it (Niklas & Spatz 2012). On the other hand and much more importantly, the geometrical size properties of the load-carrying parts of a cross-section are much more important than the material properties (Rinn 2013): the load-carrying capacity of a cross-section is proportional to the material strength multiplied by the diameter to the power of three (Gere & Timoshenko 1997). And this shows that, in this context, size matters much more than material quality. This is the reason why it is more important to determine the size (diameters and shape) of a cross-section and the location of defects than the material properties. Consequently, locally measured values of strength or elasticity are of relatively small importance in terms of the breakage safety issues discussed here.

An alternative approach could theoretically be to take material property values from reference tables as done by the SIA concept. However, how it becomes clear how dangerous it is to assume material properties taken from reference tables for a certain wood species, when applying the freely available SIA online tool, providing basic calculations used in the SIA concept and for SIA-pulltest calculations:

http://sia.simgruppe.de/sia.php

This online calculation basically determines the load-carrying capacity by calculating the section modulus as described above, multiplied by material property values taken from reference tables (Wessolly & Erb 1998). Applying this concept

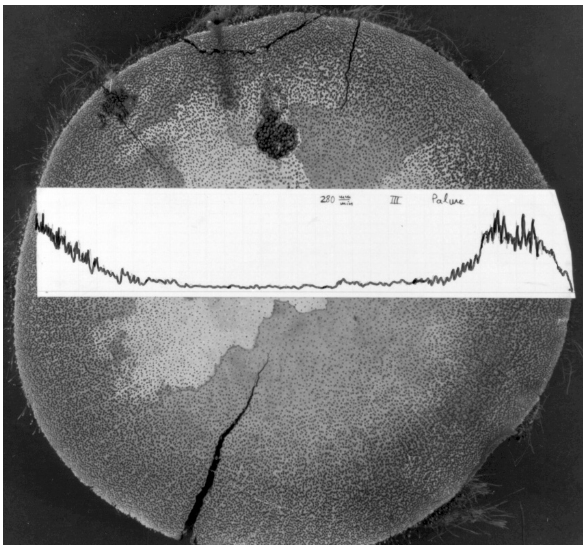


Figure 8
In stems of coconut palms, the radial density profile often shows high values on the outer 1/3 of the radius. Such density profiles can be measured by resistance drilling - but only when the drill provides a profile with a high resolution and high correlation to wood density ($r^2>0.8$; Rinn 2016), because only then the profiles correctly reveal wood density along the needle's path of penetration. The profile shown here was obtained by using a 'real' RESISTOGRAPH®. This special kind of electronic recording resistance drilling device was developed after two of the method's inventors (KAMM&VOSS) realised that mechanical and spring-driven recording of penetration resistance systematically delivers erroneous profiles leading to wrong evaluations of the wood condition. Knowing this, it would have been irresponsible to sell such kinds of resistance drilling devices and in consequence, KAMM&VOSS developed a system with electric recording and applied for a patent (Kamm & Voss 1985). This was then further developed to electronic recording and the machines were later branded with "RESISTOGRAPH®", a trademark since registered in 39 countries.

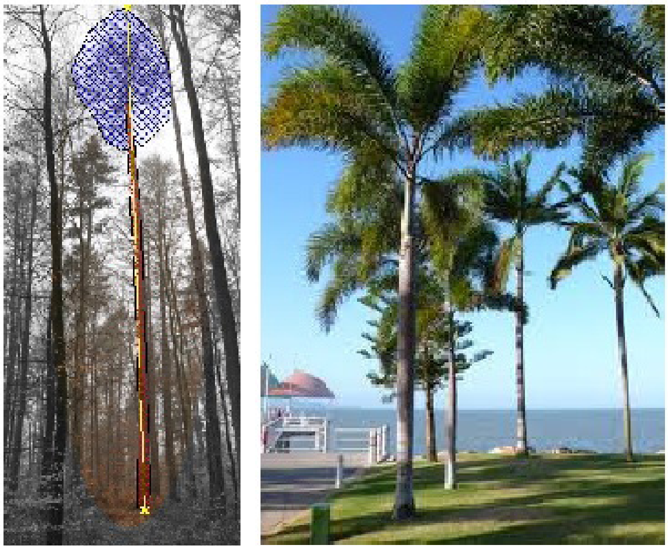


Figure 9
When comparing typical coconut palms and slender conifer forest trees, allometric properties such as tree-height to stem diameter at breast height as well as crown size, the relationships seem to be quite similar. Consequently, the fact that coconut stems provide high density wood on the outer 1/3 of the radius (and can be very soft in the center) is seen as a confirmation that such kinds of mechanically wind-loaded structures need the outer 1/3 of the radius to be intact and strong in order to be sufficiently safe against wind bending.

Figure 10
Stem cross-sections typical for mature urban trees to be inspected in terms of safety: the cross-sections are commonly not circular and the defects mostly located off-centre. Such cross-sections provide many different radius values and many different shell wall thicknesses (t), often ranging from zero (t=0) to fully wooded (t=Radius). Consequently, there is no typical or average t/R that could be quickly determined at the tree. Minimum, maximum, or average t/R values do not represent the load-carrying capacity of such cross-sections and thus, the 1/3-rule does not apply to this kind of tree.

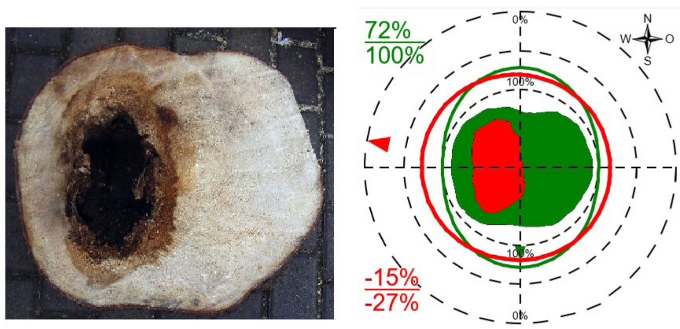
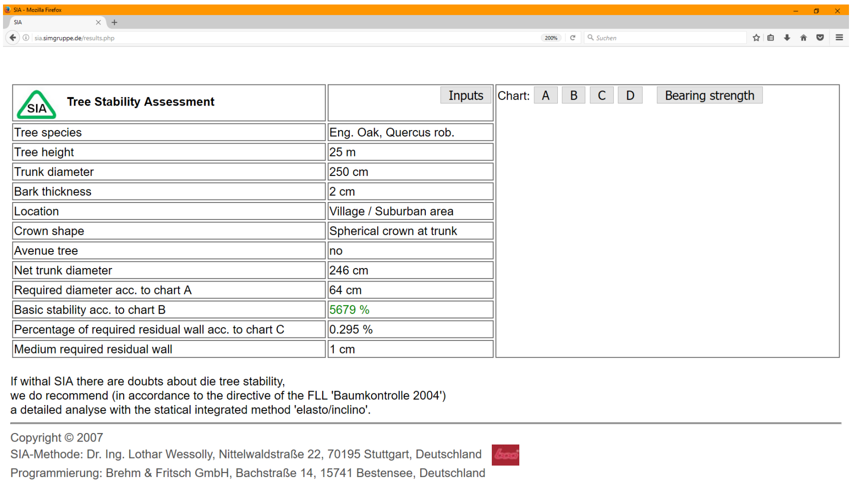


Figure 11
For evaluating the loss of load-carrying capacity of such a relatively simple non-circular cross-section with an off-centre defect, a local measurement of shell-wall thickness is not sufficient and the 1/3 rule cannot be applied in any reasonable way. When no sonic tomography is available or too expensive, a few resistance drillings can help with the drawing of a sketch of the cross-section by hand on a smartphone app (right). This allows us to determine the loss in load-carrying capacity for a better evaluation of tree safety. In this case, the defect leads to a loss in load-carrying capacity of approximately 26% for winds from the East and ~15% for winds from North and South. This aspect shows how difficult or even impossible it is to determine the breaking safety of such a cross-section with any kind of method by measuring only at one point (resistance drilling, pull-testing, increment core cracking). Without knowing the internal situation and the loading direction with the biggest losses in load-carrying capacity, it is impossible to determine the safety of such a tree. The tree would have to be pulled into several directions (preferably using four strain sensors at different heights) in order to determine the most dangerous loading direction. This is commonly far too expensive and thus impractical. In addition, for evaluating the meaning of strain-measurements, reference values are required that might not be applicable to the specific tree for evaluation (Fig. 12). Thus, pulling-tests are not a solution for such kinds of breaking safety evaluations.



Tree Stability Assessment	Inputs · Chart: A B C D · Bearing strength
Tree species	Eng. Oak, Quercus rob.
Tree height	25 m
Trunk diameter	250 cm
Bark thickness	2 cm
Location	Village / Suburban area
Crown shape	Spherical crown at trunk
Avenue tree	no
Net trunk diameter	246 cm
Required diameter acc. to chart A	64 cm
Basic stability acc. to chart B	5679 %
Percentage of required residual wall acc. to chart C	0.295 %
Medium required residual wall	1 cm

If withal SIA there are doubts about die tree stability,
we do recommend (in accordance to the directive of the FLL 'Baumkontrolle 2004')
a detailed analyse with the statical integrated method 'elasto/inclino'.

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SIA-Methode: Dr. Ing. Lothar Wessolly, Nittelwaldstraße 22, 70195 Stuttgart, Deutschland
Programmierung: Brehm & Fritsch GmbH, Bachstraße 14, 15741 Bestensee, Deutschland

Figure 12
This SIA-Online Form can be used for free and allows us to determine the so-called "Basic stability" (=breakage safety factor of the tree with an intact stem) as well as the "Medium required residual wall" for sufficient safety. For the oak tree shown in Fig. 3 with a total height of more than 25m and a stem diameter of 2.5m (~100"), this minimum wall-thickness has to be 1cm (0.4") according to SIA for sufficient safety. This obviously incorrect result is a consequence of inappropriate reference values and the fact that the section modulus does not correctly reflect the load-carrying capacity of thin-walled wooden tubes as can be seen in Fig. 6.

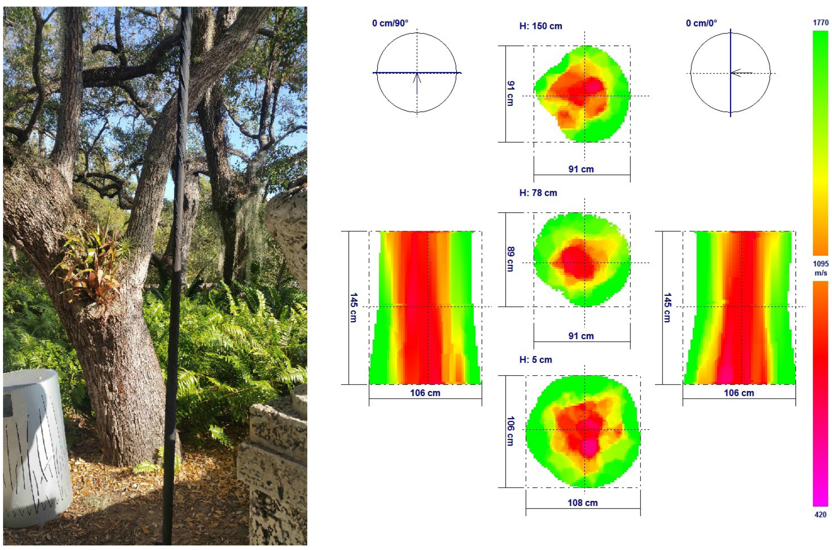

Figure 13
This tree has been standing close to a subtropical coastal shore line for more than 120 years. As shown by the sonic tomogram, the stem is severely damaged and and has been hollow for decades. But, the tree survived dozens of hurricanes while young intact trees in the same area broke. This confirms that the older trees are, the higher their basic safety and the more decay the can tolerate without being significantly more susceptible to breakage.

to the oak tree shown above (Fig. 3) leads to an interesting result (Fig. 12) for sufficient breaking safety: "Medium required residual wall = 1cm". This obviously incorrect result is a consequence of mainly two reasons:

- material property reference values (stiffness, critical strain, and drag coefficient) do not need to be correct for the specific tree (Spatz & Pfisterer 2013);
- the real load-carrying capacity of hollow wooden cross-sections is significantly smaller when calculated by the section modulus (Fig. 4) soon as $t/R<1/3$ (Fig. 6).

In consequence, the SIA concept overestimates the real load-carrying capacity by at least a factor of 10 and should thus not be applied for safety-related evaluations of such kinds of trees. However, there are some aspects to be recognised and acknowledged within the SIA concept (Wessolly 2005):

- Breakage safety is not only determined by the relative loss in load-carrying capacity of a cross-section but is always a result of comparing load-carrying capacity with the real load the tree is facing (However, doing this in absolute numbers does commonly not work as shown in Fig. 12).
- Mature trees can provide a much higher basic safety compared to younger trees (due to their age).

The load on a common urban tree mainly comes from wind and is proportional to height (H) of the tree to the power of three (Rinn 2014a). Interestingly, the load-carrying capacity of the stem cross-sections depend on the diameter (D), similar to the way wind-load depends on total tree height (H). In consequence, D^3/H^3 can be used as a measure for tree safety, not in absolute numbers (as shown above), but by observing relative changes of this ratio over time (Rinn 2015). The fact that trees try to keep H/D constant for decades after the juvenile growth phase (Kahle et al. 2008) can thus be interpreted as their desire to keep a constant safety factor ($\sim D^3/H^3$) for this period of the tree's life-time. But, as soon as tree height is not increasing any more (typically 60 to 80 years of age for common urban broad-leaved trees), trees still annually put on a new growth layer and thus continue growing in girth. Consequently, the older that mature urban trees are, the higher their basic safety factor and the more defects they can tolerate (Fig. 13) because of the continuously increasing basic safety ($\sim D^3/H^3$). Taking into account this aging effect allows us to determine the gain in safety for any kind of mature tree (Fig. 14) and thus allows us to find out the extent of defects that can be tolerated without having an increased probability of failure. In consequence, in many if not most of the mature trees we inspected in the last years, there was no need for pruning (for wind-load reduction) or need to recommend any other kind of mitigation measures, leading to many positive effects:

- less money needed for pruning and
- cabling;
- less damage to vitality and to the tree's power of resistance against fungal decay;
- longer and cheaper conservation of mature and ancient trees as important natural habitats, not only in urban areas.

Summary and conclusions

The 1/3-rule correctly reflects the fact that the load-carrying capacity of circular cross-sections with centrally located voids drops down more strongly as soon as the ratio of shell-wall-thickness (t) over radius (R) goes below 1/3. This "turning point" in the curve of the section modulus (Fig. 4) equals a loss in load-carrying capacity of approximately 20%. But, from this point on, the section modulus calculation gets increasingly incorrect when determining the relative loss in the load-carrying capacity of a cross section due to internal defects (Fig. 6), because wood is a non-isotropic material, specially weak for shear and torsional stresses. That means, the 1/3-rule is a valid and important aspect for understanding the general properties of a certain kind of loaded, defective stem cross-section.

But, for safety assessments of the typical mature urban trees, the 1/3 rule usually cannot be applied because the cross-sections to be evaluated are commonly not circular and the defects are usually not located in the centre. Such cross-sections can be evaluated only when applying tomographic approaches, revealing a relative loss in load-carrying capacity as compared to the fully intact cross-section. But, this is only one input parameter when evaluating safety, because the load has to be taken into account as well and thus, the height and the approximate age of the tree have to be determined. Doing this in absolute numbers (like SIA) can

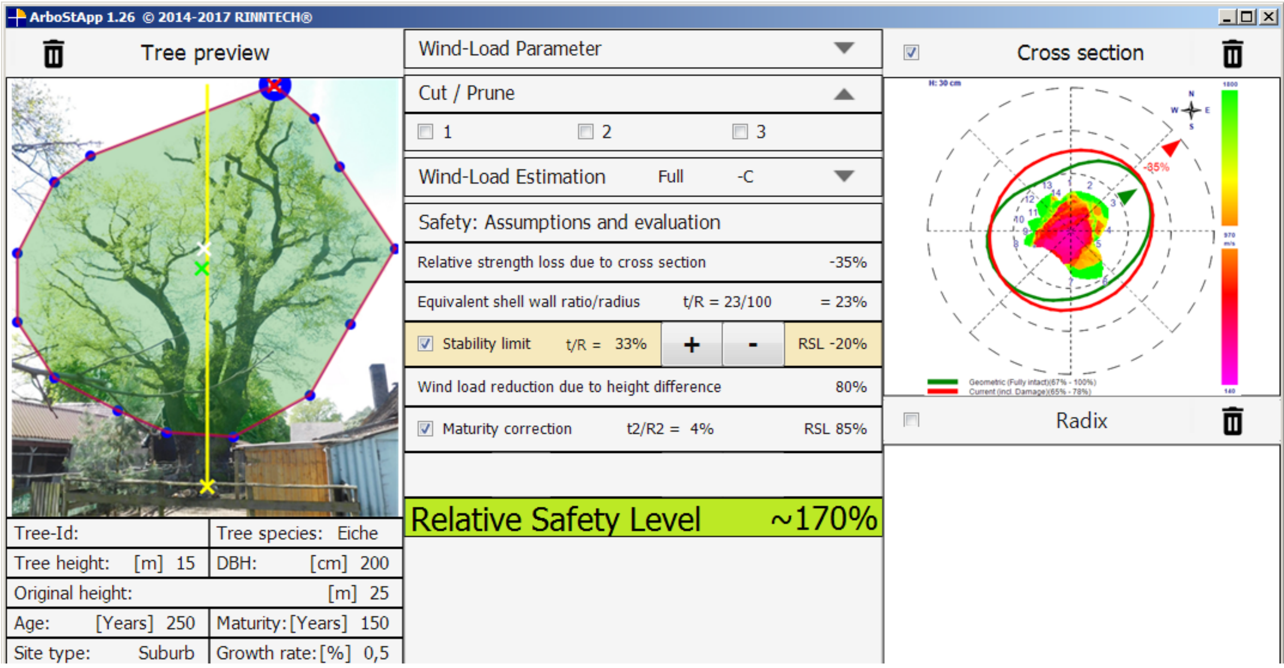

Figure 14

Example of a smartphone application estimating the relative breakage safety level of the stem of a mature oak (Quercus robur). The key factors are original/ maximum and current tree height (Rinn 2013, 2014a), tree age, and years of maturity (after having reached maximum tree height). Although this stem cross-section lost about 35% of load-carrying capacity due to the obvious defects (equalling approx. t/R~23%), the remaining safety level is still significantly higher than a young intact tree (100%). Due to the reduced height (originally ~25m, now ~15m) and the age-effect (increasing girth since height growth stopped, thus for about ~150years), the tree gained approximately 165% additional basic safety. Subtracting 35% due to the defect, still leaves approx. 170% and shows that there is no need for further crown reduction – although more than 60% of the cross-sectional area is hollow or decayed. However, when the load-carrying parts of such stem cross-sections get segmented, symmetric pruning and static crown cabling may be required in order to prohibit branch failures from torsional stresses.

deliver worthless or even dangerous results, as shown in Fig. 12.

Thus, relative approaches, looking for changes in the major factors over time (tree height and breast height diameter) are more appropriate as shown above: as soon as trees no longer grow in height, their basic breaking safety increases annually because the load-carrying capacity of the trunk depends on stem diameter taken to the power of three. Even tiny radial growth rates thus lead to a significant increase of the load-carrying capacity. Consequently, depending mainly on age, the changes in diameter and crown height over time lead to the fact that mature trees can tolerate significantly more and bigger defects without being more likely to break as compared to young (and even intact) trees. An uncountable number of mature trees, hollowed out over decades but surviving strong winds prove this as a fact. Fortunately, the increase of the basic breaking safety (as a function of age and growth rate) as well as the loss in load-carrying capacity can be estimated using smartphone applications (Fig. 14) at the tree without need of external reference data (as used by SIA). Applying this safety evaluation concept to mature trees in the last years, has mostly led to no, or significantly less, pruning required because of breakage safety concerns, which is positive in many ways: it saves money and does not further reduce the tree's capabilities to defend against fungal decay (Boddy & Rayner 1983).

The director of the urban tree department of a German town recently wrote shortly before retiring: "After having applied this 'new' (RINN-) concept of tree-safety evaluation for several years, we can state that we kept many trees much longer than we would have done before, we spent much less money for tree care (pruning and cabling) while preserving a more natural urban environment and habitat - without having more failures. That means, more benefits for less money."

Literature

Boddy, L., Rayner, A.D.M. (1983): Origins of decay in living deciduous trees: the role of moisture content and a re-appraisal of the expanded concept of tree decay. New Phytol. 94(4): 623-641.

Blass, H.-J., Schmidt, M. (1998): Querzugfestigkeit von Vollholz und Brettschichtholz. Versuchsanstalt für Stahl, Holz und Steine. Universität Karlsruhe.

Fink, S. (2009): Hazard Tree identification by Visual Tree Assessment (VTA): Scientifically solid and practically approved. Arboricultural Journal 32.3, pp. 139–155.

Gere, J. M., Timoshenko, S. P. (1997): Mechanics of Materials, PWS Publishing Company.

Gruber, F. (2007): Die VTA-0,32-Restwandstärkenregel, wissenschaftlich unhaltbar und praktisch unbrauchbar. Agrar- und Umweltrecht 37/1, 7-12.

Gruber, F. (2008): Untenable failure criteria for trees: I. The residual wall thickness rule. Arboricultural Journal 31:5-18.

Gruber, F. (2008): Reply to the responses of Claus Mattheck and Klaus Bethge to my criticisms on unteneable VTA-failure criteria – Who is right and who is wrong? Arboricultural Journal 2008/12/01. Taylor & Francis. 277-296.

Kahle, H.-P., H. Spiecker, R. Unseld, P.J. Pérez Martínez, J. Prietzel, K.H. Mellert, R. Straussberger, K.E. Rehfuess (2008): Temporal trends and spatial patterns of height growth changes in relation to changes in air temperature and precipitation, and in relation to levels of foliar nitrogen and nitrogen deposition. In: Causes and Consequences of Forest Growth Trends in Europe - Results of the Recognition Project, Chapter: 4.2, Publisher: Brill, Editors: Kahle, H.P.; Karjalainen, T.; Schuck, A.; Ågren, G.I.; Kellomäki, S.; Mellert, K.H.; Prietzel, J.; Rehfuess, K.E.; Spiecker, H, pp.127-167.

Kamm, W., Voss, S. (1985). Drill resistance method and machine. German and inter-national patent application (DE3501841A1). [This patent was later declared in-valid because of previous publications from Japan, USA, and Germany].

Ledermann, M. (2003): Beiträge zur Optimierung von Faserverbunden nach dem Vorbild der Natur. Dissertation. Universität Karlsruhe, ISSN 0947-8620, pp121.

Lesnino, G. (2009): Vergleichsuntersuchungen zur Sicherheitsermittlung an Bäumen - Schalltomografie und Zugversuche. Baumtage-Süd. Böblingen.

Mattheck, C.; Bethge, K.; Erb, D. (1993): Failure criteria for trees. Arboricultural Journal, Taylor & Francis, 17 (1993): 201-09.

Mattheck, C., Breloer, H. (1993): Handbuch der Schadenskunde von Bäumen. Der Baumbruch in Mechanik und Rechtsprechung. Rombach. Freiburg/Breisgau 1993.

Mattheck, C., Breloer, H. (1994): The body language of trees. A handbook for failure analysis. Research for Amenity trees No. 4, HMSO Publications Centre. London 1994. ISBN 0-11-753067-0.

Mattheck, C., Bethge, K. (2008): Abridged response to the criticism of VTA-failure criteria by Franz Gruber. Arboricultural Journal 31(4). December 2008.

Niklas, K.J. (2000): Computing factors of safety against wind-induced tree stem damage. Journal of Experimental Botany 51(345):797-806.

Niklas, K., Spatz, H.-C. (2012): Plant physics. Plant Physics. Univ. of Chicago Press. ISBN-10: 0226586324.

Niklas, K., Speck, T. (2001): Evolutionary trends in safety factors against wind-induced stem failure. American Journal of Botany 88(7):1266-1278.

Rinn, F. (1988). A new method for measuring tree-ring density parameters. Physics thesis, Heidelberg University, 85pp.

Rinn, F. (1990). Device for material testing, especially wood, by drill resistance measurements. German Patent 4122494; Publication-No. D84122494 84. Application 03 September 1990. pp.10.

Rinn, F. (1999): Device for investigation materials. US-Patent US6813948; in-ternational Patent PCT/DE00/01467 (1999.05.11).

Rinn, F. (2012). Basics of typical resistance-drilling profiles. Western Arborist. Winter 2012, pp. 30-36.

Rinn, F. (2013): Shell-wall thickness and breaking safety of mature trees. Western Arborist, Fall 2013, 40-44.

Rinn, F. (2014a): How much crown pruning is needed for a specific wind-load reduction? Western Arborist Spring 2014, 10-13.

Rinn, F. (2014b): Central Basics of Sonic Tree Tomography. Journal of the Society of Commercial Arborists (SCA-Today), Dec 2014, Vol. 19, No. 4, pp. 8-10.

Rinn, F. (2015): Understanding size-related principles of tree growth for tree-risk evaluation. Western Arborist Winter 2015, 14-17.

Rinn, F. (2016): Intact-decay transitions in profiles of density-calibratable resistance drilling devices using long thin needles. Arboricultural Journal. Volume 38, 2016-4. 204-217.

Scatter, S., Kucera, B. (2000): Tree breakage from torsional wind loading due to crown asymmetry. Forest Ecology and Management. Volume 135, Issues 1–3, 15 September 2000, Pages 97–103

Spatz, H.–C., Niklas, K.-J. (2013): Modes of failure in tubular plant organs. Am. J. Bot. Feb; 100(2): 332-6.

Spatz, H.-C., Pfisterer, J. (2013): Mechanical properties of green wood and their relevance for tree risk assessment. Arboriculture and Urban Forestry 39(5), 218-225.

Wessolly, L., Erb, M. (1998): Handbuch der Baumstatik und Baumkontrolle. Patzer Verlag

Wessolly, L. (2005): Bäume dürfen hohl sein. BAUMZEITUNG (5):27-28.

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