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Statics Integrated Methods

Results from pulling tests in the past decades

More than 4.800 pulling tests were performed by certified expert witnesses according to the Elasto-Inclinomethod. Data derived from these assessments allows for a deeper understanding of failure potential in mature and old ornamental trees. The integration of biological and mechanical aspects question the suitability of formulas that assess tree hazard by the geometry of the stem only.

Tree statics was introduced in the 1980´s when Dr. L. Wessolly, a leading scientist from the University of Stuttgart, and G. Sinn, a landscape architect, worked on a tree friendly assessment method (international publication in SINN & WESSOLLY 1989). Dr. Wessolly and his team based their calculations on international engineering conventions for the stability assessment of any structure designed to carry load.

In contrast to other methods tree statics considers three major components: load, form and material. Trees are loaded primarily by wind gusts, and wind is the most common reason for their failure. Form and diameter of the stem and its degree of hollowness identify the geometry of the load bearing structure.

The engineering safety assessment is based on the question whether or not the wind load in a gale causes critical deformation in the stem's marginal fibers or in the anchoring root system. Therefore the specific material properties (compressive strength, Young's modulus, limit of elasticity) of green wood were identified (WESSOLLY 1995a). The uprooting process was recorded in numerous tests that comprised different species and site conditions (WESSOLLY 1996).

As the trunk moves in a storm, its marginal fibers stretch on the tension side and compress on the opposite. This strain can be measured with a sensitive instrument called elastometer (resolution 1/1000 mm). Under load the anchoring roots near the stem bend, allowing the trunk and the whole root flare to lean. Only another special instrument (inclinometer, resolution 1/100°) can sensor this invisible reaction.

Once a tree is considered hazardous after visual inspection it can be tested for it's stability by carrying out a tensile static load test, also known as pulling test. The procedure focuses on two major types of failure. The fracture safety of the stem is derived from recording the strain exerted in the marginal fibers (Elastomethod). The safety against uprooting can be determined by analyzing the root flare's inclination under the applied substitute load (Inclinomethod).

Both methods require a load analysis according to engineering standards (DIN 1055 and DIN 1056 modified for trees). BRUDI (2002) contains a detailed description of static integrated methods (SIM) and the procedure of a pulling test according to the Elasto-Inclinometod in Spanish.

Figure 1

Statics integrated methods distinguish two major hazards: tipping over and stem fracture.

Most other failure potentials (branch fracture, fork splitting) can be visually detected and thus be prevented by arboricultural measures (bracing or pruning) without substantially affecting a tree's biology.

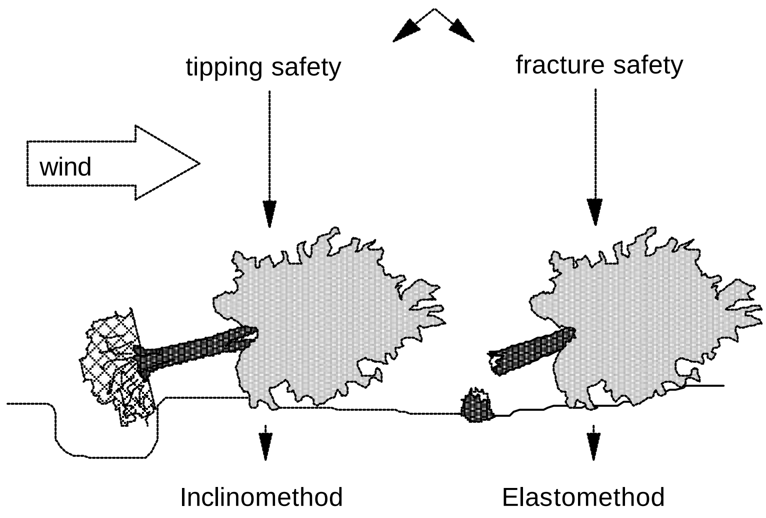
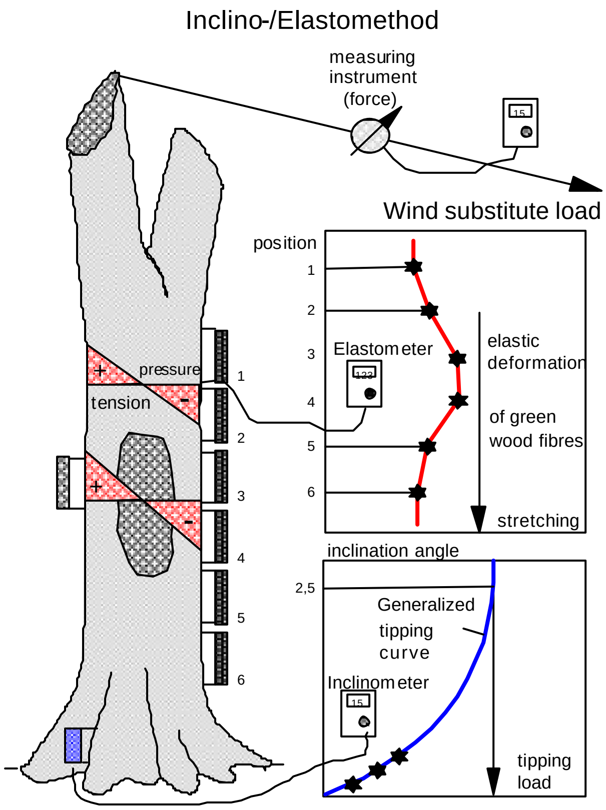


Figure 2



Static load tests are common procedure in engineering when the stability of a load bearing structure cannot be determined from construction drawings.

That is why also airplane prototypes have to undergo load tests. It is not reliable to assess their stability purely from static calculations. Therefore load is applied to their wings and the deformation of the material is measured with highly sensitive strain gauges.

In a pulling test the tree is subjected to a substitute load and its reaction is measured with high resolution sensors for strain in the stem's marginal fibers (Elastometer) and inclination of the root flare (Inclinometer).

Since the beginning of tree statics the results from pulling tests carried out by members of SAG Baumstatik e.V.* were collected and statistically processed. Up to now more than 4800 trees were tested for their stability. Dr. Wessolly and his team consistently evaluated data and processed diagrams and tables (WESSOLLY 2004).

This paper presents a selection of results from Dr. Wessolly's publication and derives conclusions for an accurate tree assessment by integrating mechanical and biological aspects.

* This association of court-certified expert witnesses on tree hazard assessment has currently about 40 members in 10 different countries. All of them apply statics integrated methods (SIM).

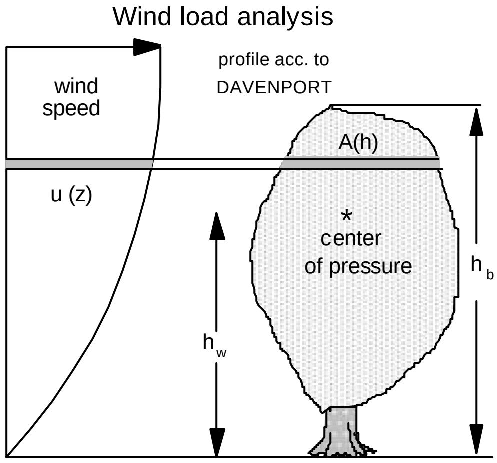
Wind load and its influence on tree stability

In general, wind load enhances exponentially with increasing tree height. At higher levels the wind gains much greater speed due to less resistance from the terrain and less turbulent flow. For solitary trees the wind speed can be simulated using profiles proposed by DAVENPORT (1965). This model is adapted for urban areas by using correction factors that incorporate blast pipe effects and turbulences around buildings according to the work of ZURANSKI (1966) and KAMEI et al. (1979).

Figure 3

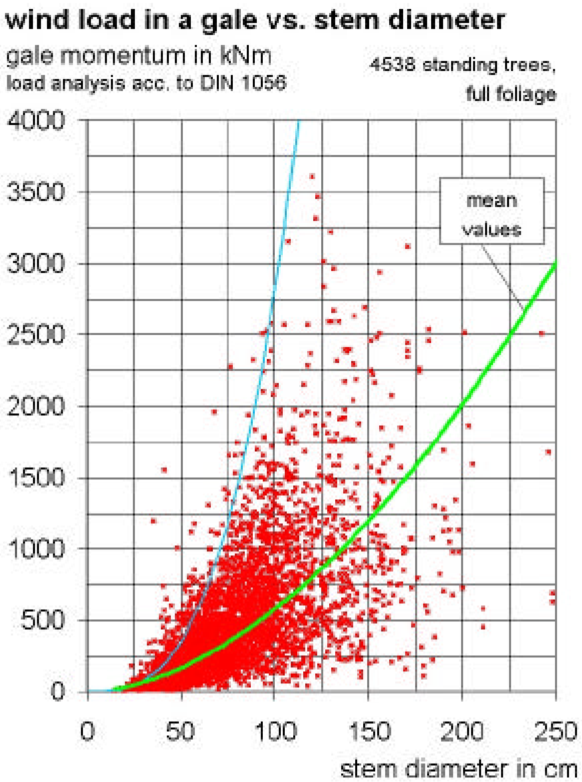
Wind speed enhances with increasing height. Therefore the wind pressure is calculated separately for crown areas at a certain height. Adding up forces and levers produces a total wind pressure and determines an excentric load centre.

To adjust this standard procedure to trees specific factors (aerodynamic drag in tree crowns, enhancing effects due to oscillation) were incorporated in the original equations.



The overview of load assessments for more than 4.500 trees in full foliage shows an increasing wind load for higher trees (WESSOLLY 2004). At the same time the resulting momentum in storm (level 12 on Beaufort's scale, wind speed 32,5 m/s) varies significantly in proportion to the stem diameter. For trees of 1 m diameter the actual wind loading ranges within a factor of 12. Consequently the wind load can not be derived from the diameter a tree's stem has gained.

Figure 4



Due to the great variability a proper wind load assessment is required. Standard engineering procedures consider major factors such as height, surface area, air density, aerodynamic drag factors, roughness of terrain and exposure.

Obviously a tree's stem diameter does not indicate the load its crown is exposed to. This is due to the tree's biology which governs diameter increase beyond the influence of mechanical factors.

Especially older trees form new layers of wood not mainly in response to mechanical stimulation like described in young plants (thigmomorphogenesis).

Basic safety and failure potential

According to current models a tree's growth in height seems to be limited by hydraulic and biological constraints (NIKLAS & SPATZ 2004). But because of their biology trees never really cease to grow in diameter. If its stem was solid, a big ornamental tree could usually resist much greater loads then it might ever experience from wind.

The basic safety of a tree compares the assessed loading of the crown by a gust of hurricane speed (level 12 on Beaufort's scale, 32,5 m/s) and the load bearing capacity of the tree's stem if it was solid. It is a simple measure for the initial safety against fracture a tree has gained due to its diameter growth (WESSOLLY 1995b).

Naturally aging trees are susceptible of decay caused by fungi and a hollow stem is very common. But from basic mechanics it becomes clear that a thicker stem can carry much more flexural load. Therefore it can tolerate more decay and deal with thinner residual walls. If safety assessments are based on the amount of strength loss due to decay it is essential to consider the initial load bearing capacity of the stem and the actual wind load (WESSOLLY 1995c, KANE et al. 2001).

Figure 5

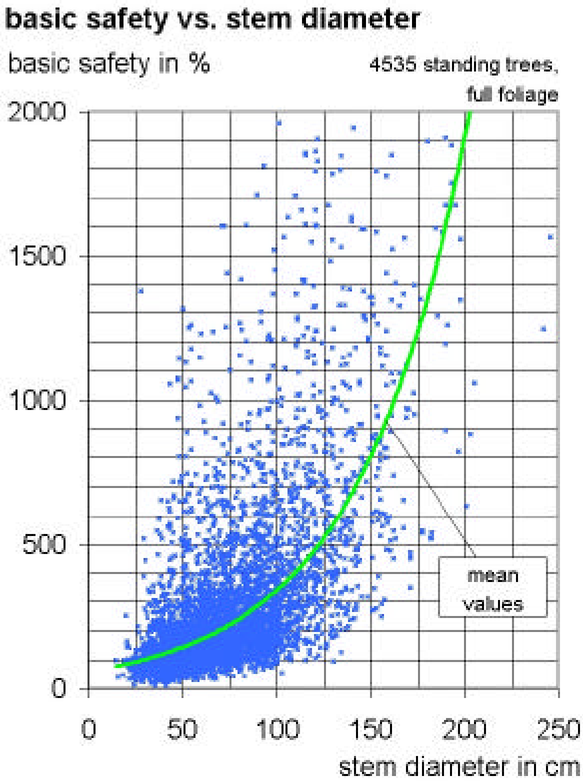


Figure 5 shows an exponentially increasing basic safety with greater stem diameter. Physiological effects explain this trend.

Young trees have limited photosynthetic capacities and therefore focus on gaining height. Their stability relies mainly on pretensions in the still solid stem.

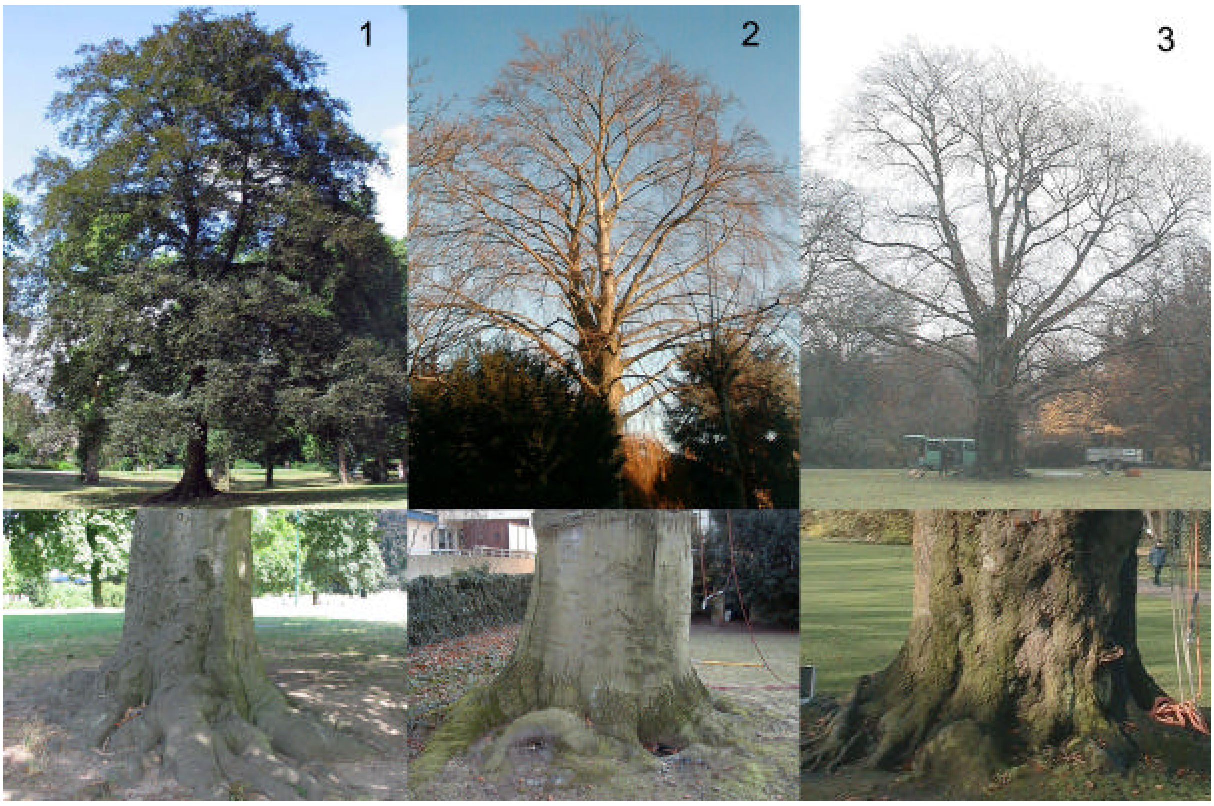
Later a greater leaf area is exposed to the light and the tree can produce a sufficient amount of fibers to gain thickness and compensate for decay.

Because growth in height almost terminates after maturation, the load remains constant. But even old trees continue to produce growth increments every year. Therefore they gain diameter and might balance strength loss due to decay as long as their vigour is not significantly affected.

The 70% rule and its suitability for ornamental trees

In the following example load and size independent critria for tree hazard assessment is applied to three different European beeches (Fagus sylvatica L.). They are of similar height and crown area (figure 6). Because they grow in comparable terrain (parks), the wind load is almost the same. They only differ in stem diameter. Tree 1 has a diameter of 113 cm, while tree 3 has gained a diameter of almost 2 m. Consequently their basic safety is very different. It ranges from 210% to almost 1.300%, indicating a very high potential of trees no. 2 and 3 to compensate for decay.

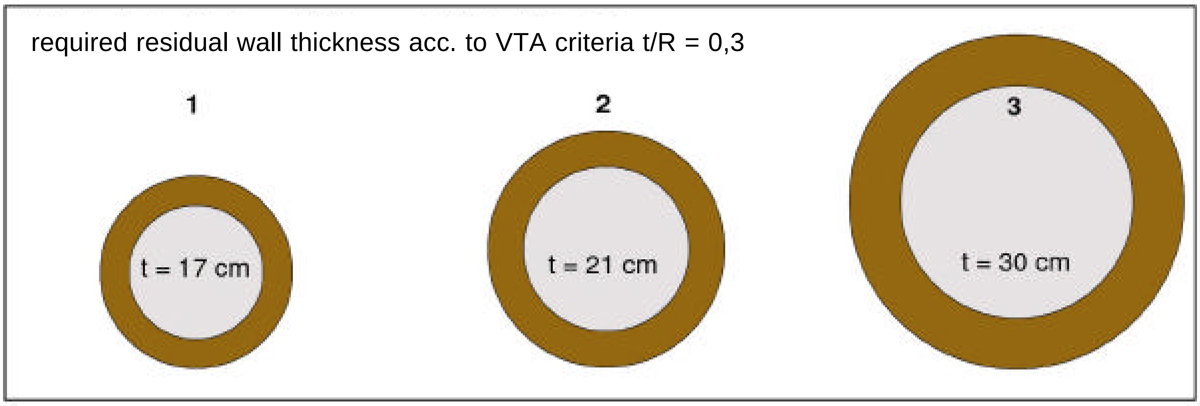
Figure 6



height	25,5 m	24 m	23,5 m
stem diameter	113 cm	139 cm	197 cm
basic safety	210 %	490 %	1.290 %
fracture safety at t/R = 0,3	140 %	326 %	860 %

If the 70% cavity criterion or 1/3 ratio* was valid, tree no. 3 required a residual wall of 30 cm. The slender tree no. 1 would be safe with only 17 cm wall thickness, even though it is already less resistant to wind due to its smaller diameter. The assumption that a tree with greater diameter should require thicker walls to withstand the same load contradicts common mechanical models and all practical experience.

Figure 7



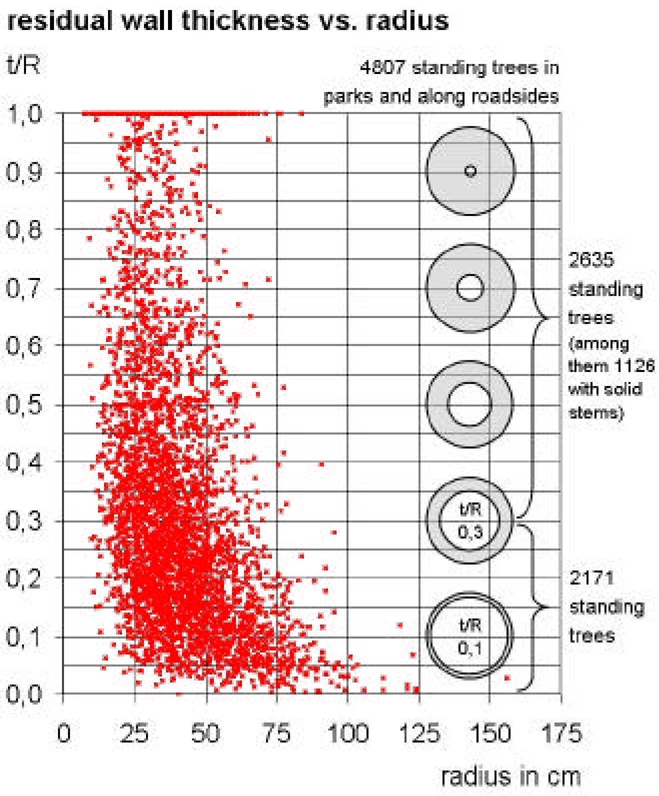
At a degree of hollowness of 70% only the safety margins of tree no. 1 would be reduced (140%). The safety of the two other trees (325 and 860%) still is significantly higher than the desired figure of 150% By engineering standards they would be considered safe against stem fracture.

* The 70% rule was first described by WAGENER (1963) for conifers in forest stands. MATTHECK et al. (1994) report its general validity to angiosperms and ornamental trees outside forests stands.

Tree hazard assessment mainly deals with mature, old or even veteran trees. Mostly these trees are ornamental trees in gardens, parks or along roadsides. There age, size, strength and wind loading vary over a wide range. Therefore it is not possible to assess their stability with simplified criteria based only on stem geometry.

Pulling tests with the Elasto-Inclinomethod incorporate many of the specific parameters that affect a tree's safety against failure due to wind. They also allow for determining the thickness of residual walls without the use of invasive instruments. Figure 8 shows results from over 4800 trees tested individually for their stability. Each test is documented in form of a written expertise. This extensive data pool contradicts any general rule to classify a tree as hazardous by the geometry of its stem alone.

Figure 8 degree of hollowness



4.800 pulling tests according to the Elasto-Inclinomethod did not reveal any indication that standing trees require a residual wall thickness of more than 30% of the stem radius.

The degree of hollowness was non-destructively derived from Elastometer readings during static load tests on standing trees. The values vary over a wide range and do not show a significant limit at any t/R ratio.

Conclusion

Proper tree hazard assessment does not generally require pulling tests. But practitioners should always incorporate the three elements of statics in the diagnosis of failure probability: load, form and material. Focussing on one of these elements only contradicts practical experience. This leads to unnecessary felling and might as well underestimate a potential risk of failure.

Static integrated methods reveal a tree's potential to fail due to uprooting or stem fracture in a gale. They apply international engineering standards. This enables owners to conserve trees as long possible and detect actual hazard. Data derived from 4.800 pulling tests confirms that mature trees are able to gain high safety reserves due to the scaling of crown area and stem diameter. The results do not indicate any critical degree of hollowness that was generally valid throughout the broad variety of species, shapes and sites.

Quotations

All diagrams and pictures contained in this paper are excerpts from published and unpublished work by Dr. L. WESSOLLY, Stuttgart, and reprinted here by his kind permission.

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