How hollow may a tree be?

NEUE LANDSCHAFT 11/96 S. 847 - 850
TUIN & LANDSCHAP 15/1998 S. 18 - 21

More than two thousend investigations of tree statics form the basis for answering the question as to how safe a hollow tree is:

a report by Dr.-Ing. Lothar Wessolly of Stuttgart

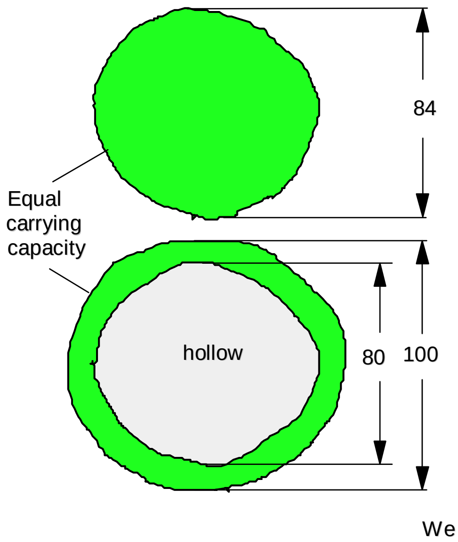


Fig.1. Carrying capacity of astem cross-section. Both cross-sections are carrying the same amount. The actual degree of hollowness is unimportant. These cross-sections are also found one above the other in the tree. It has made good ist static deficit in the region of the cavity by increased diameter growth. The visible symptom is then a sign of succesful stabilization and not of a weakness.

A tree will break in a storm if it has been released or if a fungus has made it hollow. The varying interrelated criteria for determining safety against fracture have been worked out for the first time on the basis of scientific evaluation of 2096 expert assessments of tree statics. Amazingly, the degree of hollowness or different wood strengths were only the two quite subordinate aspects of the statics triangle, which consists of load, shape and material. The size of the actual cavity provides no information on the safety of the tree.

The Statics Triangle

Wind load - Cross-sectional shape - Wood material

Determining the safety of a tree, like that of a building, is a clearly defined engineering task with fixed internationally accepted rules. It involves, on the one hand, determining as accurately as possible the forces occurring and, on the other hand, whether the structure and material can withstand them. This procedure is physically essential, and is laid down in every German Industrial Standard (DIN). It is symbolized in the statics triangle, which consists of the inseparable connection of load, shape and material.
It would naturally be simpler to determine the safety of trees if nature had kept to closely limited numerical values which could be used to describe a uniform residual wall thickness or a constant safety value valid for all trees. Even though trees as structures nearly always consist of roots, stem and crown, their diversity of form suggests a priori that it will not be possible to determine safety by generalized numerical values characterizing the degree of hollowness or safety, as used for example in the VTA method. This practical experience is confirmed by the scientific evaluation of 2096 safety assessments of tree statics.

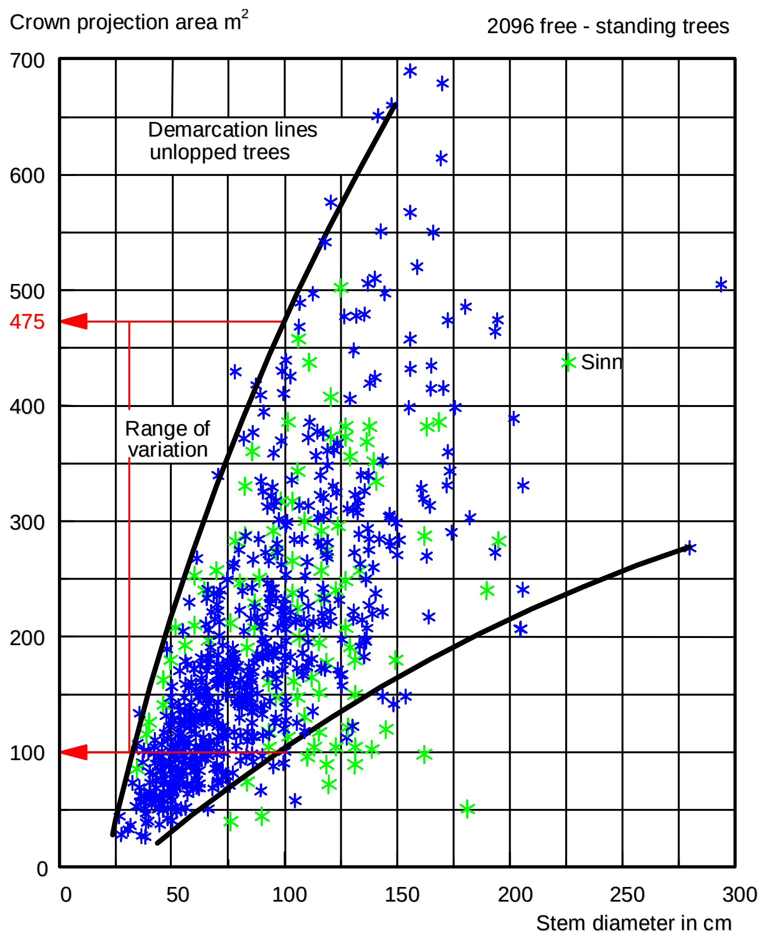


Fig. 2. Comparison of crown sail and stem diameter. With identical stem diameter the crown area of a tree of 100 cm diameter can be 100 ... 465 m^2

The Life of Trees

A young tree is primarily engaged in gaining space. It occupies rooting space and aerial space, and to do this it must necessarily neglect its safety. It sways in the wind, so that the dynamic load may even be greater than the static load.
However, it makes use of a trick to avoid becoming too dangerous: it can pre-stress itself internally and thus increase its fracture safety by up to double. But to do this it must be solid. Like the pole of a tent, the heart of the tree serves as a compression support. However, the young tree is relatively unstable and has no static reserves.
In the adult phase the tree has occupied aerial space, the crown 'sail' no longer increases disproportionately, and the tree consolidates its statics situation by diameter growth. Every year the tree becomes safer (Fig. 4) and lays down reserves for the case when, with one-hundred percent probability, a fungus will at some time or other penetrate into its interior and try to hollow it out. With the loss of its heartwood the tree loses its pre-stressing, but by then it has generally laid down sufficient static reserves on which it can subsist for a long time.

Biologically it is little affected by this at first: it is mainly the tree's outer layers which are important. Accordingly it conforms to the statics, which in optimized form always resorts to tubes with thin walls.
No-one would dream of making a bicycle of solid material. The body of a motor vehicle is also based on the load-bearing principle of 'thin tubes'.

The stout old tree can then live on a good cushion. It no longer sways in the wind, thus eliminating the dynamic parts of the load which make the slender tree put on growth. Like a tube with thin walls, it is safe. The cell growth is still just the same as in a young tree, and it keeps on growing. Even an old tree is young and vigorous in the parts that are important for its statics. The better its surroundings, the smaller are the effects on the crown and the better is the prognosis. Basically we can state that the older and thicker a tree is, the greater is its basic safety, whereas the more slender it is and the more competitively it has grown, the smaller will its safety cushion be (Fig. 4).

Evaluation of 2096 Assessments of Tree Statics

Just *as* the ratio between sail area and mast is of fundamental importance in a sailing ship in a storm, so a tree behaves in the same way: how large is the crown at a given stem diameter?

As Fig. 2 shows, the crown area of a tree can be some 4.6 times greater (465 m^2/l00 m^2 with d = 100 cm) than that of another tree of identical stem diameter.
However, the sail area is only of secondary importance, because efficiency is determined by form. Load analysis of 2096 free-standing trees (not forest trees) has revealed the great range of diversity of nature.

At the same stem diameter, one unlopped tree may have to withstand a wind load 11 times greater (2500 kNm/220 kNm) than another (Fig. 3).

Accordingly a hollow cavity can only be assessed in comparison with the basic static substance, the tree's cushion.

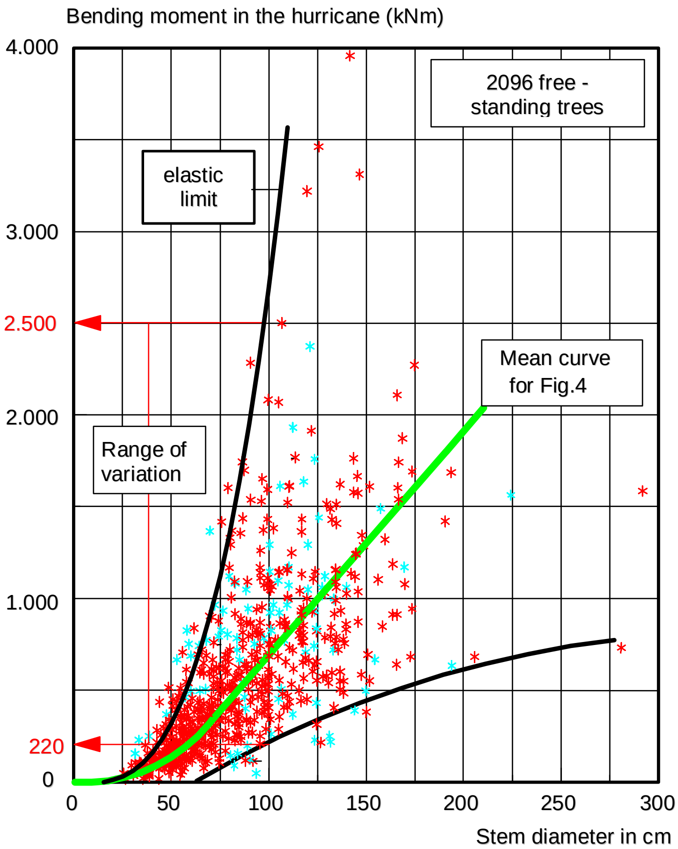


Fig. 3. Comparison of severe storm loading and stem diameter. With identical stem diameter, the storm load on a tree of 100 cm stem diameter can be 220 ... 2500 kNm. The basis of this load analysis is a refinement of the load assumptions according to DIN 1055 and 1056, defined for trees.

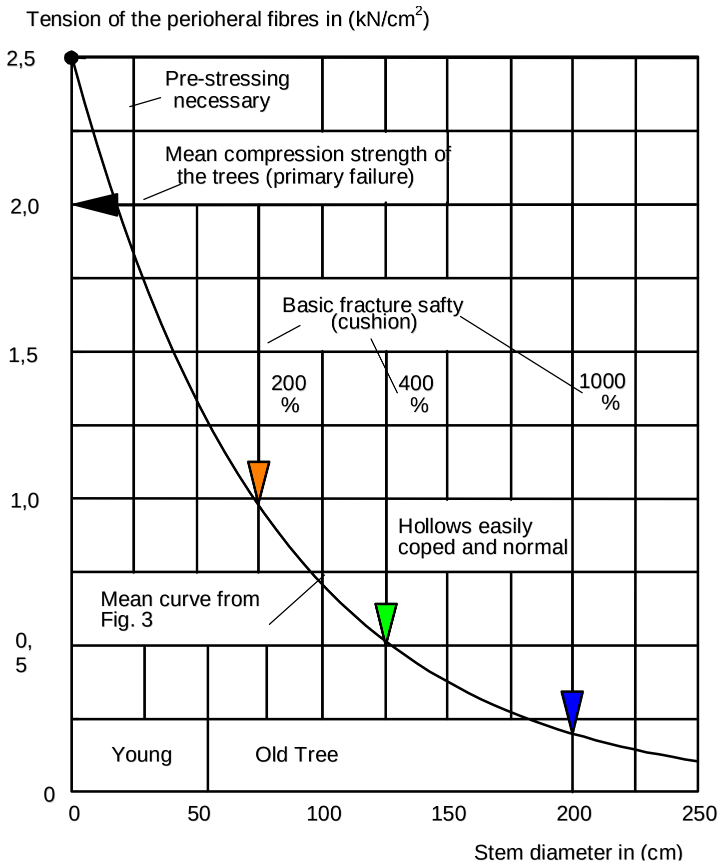


Fig. 4. Peripheral stresses in the stem in a severe storm
(mean curve re-calculated from Fig. 3, 2096 trees). The loading of the stem cross-section by a severe storm clearly decreases with increasing age. This means that the basic safety of a tree, its static cushion, increases with increasing age and diameter. It can also decay more, without becoming a safety problem (see also Fig. 6).

Influence of the Material

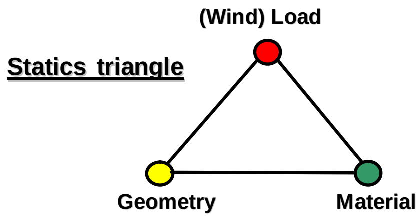
Within certain limits a tree can react to increased load by producing stronger wood. Tall slender trees tend to have higher green wood strength than more suppressed trees of the same species, and the strength increase can be as much as 100%. The compression strength of the stemwood of all the trees investigated in the Stuttgart Strength Catalogue reaches the elasticity limit between 2.8 kN/cm^2 in oak and 1.4 kN/cm^2 in horse chestnut. The average value for the trees is 2 kN/cm^2. In other words, the strengths of the tree species are very similar.

Influence of the Hollow Cavity

In recent years a wall-thickness to radius ratio of 0.3 has emerged as a safety limit. This was based on a points frequency diagram presented by Mattheck, showing an accumulation of failure beyond this limit. Unfortunately Mattheck has not yet documented or arranged the origin of his measured points, but in order to deduce a rule it is essential to show what type of trees are involved. Statistics is not a cure-all.

A tall slender tree capable of swaying is much more heavily loaded by resonances than a shorter stouter park tree or street tree. The statics of the slender tree is strongly stimulated from the start, and with the slightest impairment by a cavity it will buckle and collapse, once the stabilizing internal pre-stressing is decayed away. Fomes rot in spruce is a clear example. Only then does the frequency diagram with the massive cases of failure at 0.3 become plausible. The transfer or generalization of this diagram to street trees is scientifically inadmissible. All the evaluations of measurements presented in this paper give quite different results. This becomes particularly clear in Fig 6: of the 1366 static safety assessments, all the standing trees with reduced load-bearing capacity in the stem were identified. It emerged that the majority having extensive cavities had survived safely for decades. Only the trees below the red curve had safety problems (us) but had not yet broken off. Here it is also seen that it is mainly slender trees with cavities that get problems. The blue limiting curve shows clearly that there are no longer any solid trees beyond certain maximum stem diameters. A large hollow cavity is therefore completely natural, and not an automatic reason for felling.

Another thing should be made clear: decay up to the 0.3 limit means a reduction in load-bearing capacity of only 30 % (!) as compared to a solid stem. In a spruce tree that may already be too



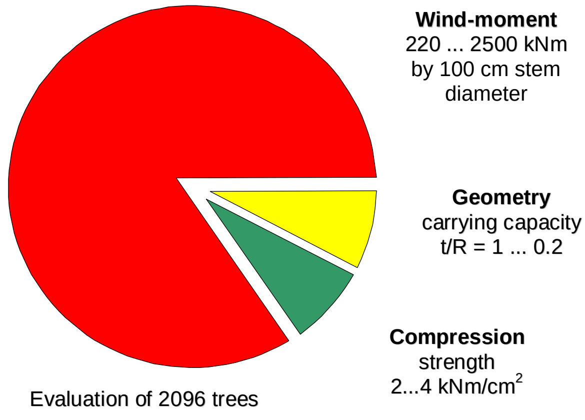


Fig. 5. Natural ranges of fluctuation and hence importance for the safety diagnosis. The relative weighting of the three components influencing the tree`s statics in accordance with Fig. 3 shows clearly that only a method of diagnosis which includes determination of wind load is capable of answering the question of the tree safty. It is not enough to determine only the cavity (yellow sector) or (if actually possible) the compression strength in the grain direction (green sector) using instruments on the standing tree, and to rank the red sector, the storm loading, merely by a glance of the crown.

much, but for an old stout-stemmed tree with solid basal statics it doesn't matter at all (Figs,4 and 6). With a scatter of basic safety of all trees of up to 1000% (one tree is 10 times safer than another at the same stem diameter), the degree of hollowness can be only a subordinate criterion in considering safety (Fig. 3). If we also consider the maximum increase in wood strength of up to 100% in severely stressed parts of trees, then we must conclude that the extent of the cavity is actually the least important of the three points of diagnosis in assessing trees (Fig. 5).

This conclusion is supported by the fact that many fullcrowned trees of more than 1 m stem diameter exhibit wall thicknesses of only 5 to 10 cm and yet have withstood all the severe storms for decades (Wessolly 1995, Fig. 6). Admittedly the danger of branch break out does exist in very hollow trees, and should be avoided by appropriate securing measures.

The Uniformity of Wall Thickness

Only for illustration, the discussion presented here is based on the assumption of uniform wall thickness. It would be wrong to conclude from this that the key diagnostic information could be provided by boring. The poor information value of borings has been reported elsewhere (Wessolly, 1995). In actual fact, uniform wall thickness is very rarely found, being approached only in spruce or in very old oaks in which the sapwood represents an insuperable barrier for the fungus. Irregular decay is the general rule.

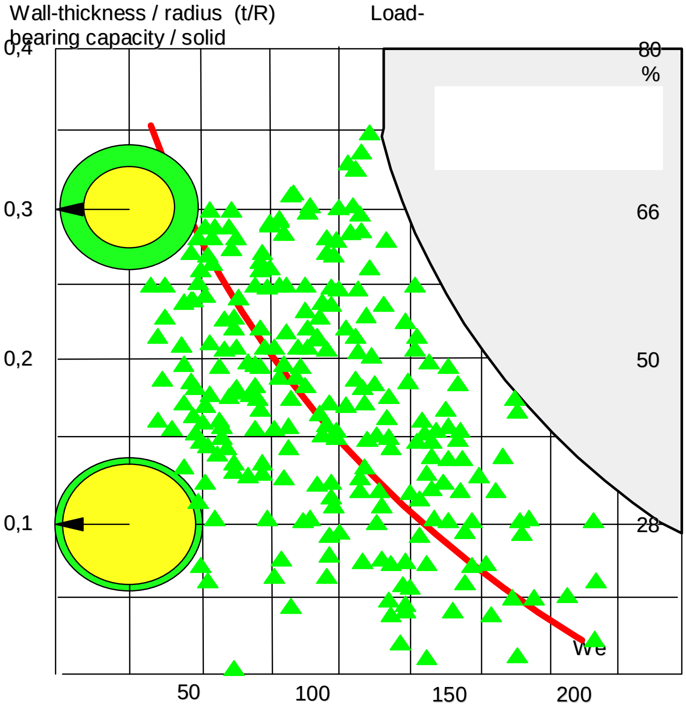
In contrast, the Elastometer has decisive advantages as a method of recording the representative stretching of the outer fibres. The reaction of the outer fibres to the tensile load contains the load-bearing capacity of all the other fibres in the cross-section, irrespective of their position. This result is valid, quite independent of cross-sectional form (Wessolly 1995). In all the results presented here, the general residual load-bearing capacity was determined against a complete cross-section and re-calculated for a uniform circular ring.

Sumary

The evaluation of traffic safety is the classical task of the tree-statics expert. First the basic stability of a tree must be determined, i.e. whether its load-bearing capacity in a severe storm is already severely stressed from the start, or its safety cushion is large. Only then does one have a reference point for the cavity, and this alone is tree statics and the only admissible safety determination. The evaluation of 2096 (solid tree safety assessments with the non-destructive Elastometer method has shown that the load analysis is by far the most important point, because the safety cushion of the tree mayvary by a factor of 11 for the same stem diameter. As expected, a fixed safety factor does not exist. In contrast, wood strengths (which could deviate from the mean value by a factor of 2) and also the degree of hollowness (with a factor of 2 at t/R = 0.2 are nearly unimportant. Accordingly, after load analysis and determination of the safety cushion we can in most cases dispense with any other instrumentation, especially injurious boring. Knowing the safety cushion of a tree will give the tree-care expert diagnostic safety. With the SIA method (Statics-Integrated Tree Assessment) the practitioner will know the basic safety of his tree within 5 minutes, and how much wall thickness it needs, without any expensive instruments. A tree survey will gain decisively in information on the important traffic safety question, if this basic safety value is entered.

Statics-integrated tree assessment (previously called SIA) developed for practical tree diagnosis, and the non destructive statics-integrated Elastometer method (Wessolly) will, in the hands of the expert, always take account of the load analysis. They thus provide the most accurate predictions of fracture safety that are possible today. The load analysis itself is a precise application of German Industrial Standard DIN 1055, 1056 taking dynamics into account.

To sum up: even a safe tree may be nearly entirely hollow. There is no fixed boundary value such as 0.3 for example. The importance of the cavity can only be assessed in comparison with the static cushion of the tree. This requires the load analysis, simplified by DIN 1055 with the appropriate cw-value or, even better, matched to trees by Statics Integreated tree assessment (SIA).



Literature

Amtmann, R. (Dynamic wind-loading of conifers).Schriftenreihe Forstw. Fak. Univ. München 74,1986.

Davenport, A.G. Rational for Determining Design Wind Velocittes. Journ. of the structural Division, Proc, ASCE, 1960, v.86.

Davenport, A.G. The relationship of wind structure to wind loading.wind effects of buil- ding and structures, v. I HMSO London 1965.

Fritz, W., & Wessolly, L. (Aerodynamics of buildings wind-tunnel investigations on model buildings). Diploma, Inst. Aerodynamik, Univ. Stuttgart, 1973.Hirtz, H. (Report on the status of work on rules for determining the effect of wind on structures). Konstruktiver Ingenieurbau, Report No. 35/36, Bochum 1981.

Hirtz, H. (Report on the work of the DIN 1055 Part 4 Committee. Aeroelastic problems outside air and space travel). Mitt. Curt-Risch-Instituts, Hannover 1978.

Höster, H.R. (Tree care and tree protection). Stuttgart 1993.

Ishizaki, H. &.Sung, I.W. Influence of adjacent buildings to wind, wind effects of buildings and structures. Tokyo 1971, p. 145.

Kamei, I. & Maruta, E. Study on wind environmental problems caused around buildings in Japan, Journal of Industrial Aerodynamics, 4, p. 1979.

Kusche, D. & Siewniak, M. (Tree care today) 3rd edition 1994.

Lesnino, G., & P. zu Glos (The Fractometer) AFZ 8/1994, p. 417.

Kollmann, F. (Technology of wood and wood-based materials). Vol. 1 Berlin 1951.

Mattheck, C., Bethge, K., & Breloer, H. (General validity of the rules for evaluating risk trees). Das Gartenamt 6/94, p. 407.

Mayer, H. (Wind and tree oscillations). Wiss. Mitt. Meteorol. Inst.Univ. München No. 35, p. 66.

Mayhead, G.J. Some drag coefficients for British forest trees, derived from wind tunnel studies. Agric. Meteorol. 12, 1973, p. 123.

Melbourne, W.H. & Joubert, P.N. Problems of wind flow at the base of tall buildings, wind effects of buildings and structures. Tokyo 1971, p. 105.

Murakami, S., Uehara, K., & Komine, H. Amplification of wind speed at ground level due to construction of high-rise buildings in urban area. Journal of Industrial Aerodynamics, 4, 1979, P 343.

Ruscheweyh, H. (Dynamic wind action on structures) 2 vols. Berlin 1982.

Schlaich, J. (On the effect of wind gusts on structures). Der Bauingenieur 41, 1966

Sinn, G. (Determining fracture safety in trees). Das Gartenamt 9/94, p. 617.

Wessolly, L. (Wind loads on trees). 11th Bad Godesberg Tree Seminar 1988.

Wessolly, L. (Material and structural features of trees. Continuation of the Stuttgart Strength Catalogue). Proceedings of the 15th Bad Godesberg Tree Seminar 1992.

Wessolly, L. (Root damage and stability of trees). Neue Landschaft 10/94, p. 853-860.

Wessolly, L. (Stability and fracture safety of trees). Das Gartenamt 8/93, p. 486.

Wessolly, L. (Fracture diagnosis of trees). Stadt und Grün 6/95, p. 416-423; 8/95 p. 570-

573; 9/95, p. 635-640.

Wessolly, L. /Erb, M. Handbook Tree-Statics and Tree - Controlling, Berlin 1998

Zuranski, J. (Wind loads on buildings and structures) Cologne 1966.