Fracture Diagnosis of Trees

Part 3:
Boring is no way for reliable fracture diagnosis

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Introduction

Here we shall ignore the fact that boring produces **embolisms** in the tree which then form a starting point for destruction by wood fungi (Liese, Dujesiefken: **'Motorways for fungi').** We shall also ignore that fact that W. Koch, the Nestor of tree evaluation, placed borings close to damage and wanted to make a deduction of 5% per bore-hole when determining value (manuscript of lecture at FH Nuertingen, 1991). We shall also ignore the fact that **ZTV Tree Care** (1992) states that preference should be given to methods which do not harm the tree (ZTV 1992; Hoester, 1993; Lesnino, 1994). And according to Shigo the tree's protective boundary should never' be pierced.

However, the latest flow-diagrams of the VTA method even include the Endoscope, alongside augers and borers (Mattheck, Bethge, Breloer, 1994, p. 407). With its drill hole of about 10 mm diameter, the Endoscope causes damage out of all proportion to the benefit, according to experts at the FLL 'Tree Statics' discussion. Even when using the thinnest drills, the intact body of wood is injured. If the compartmentalization zone against the fungus is pierced, we may expect that even the finest drill will still draw out with it the much smaller fungal hyphae when it is withdrawn from the interior. However, it is not injury by boring which will be discussed here, but rather its effectiveness for expert tree monitoring.

No scientific training is needed to understand the following discussion - sound commonsense is enough. Just remember that assessing fracture safety of a structure by all the relevant Standards is based on computational statics. This means that (1) load, (2) material and (3) geometry must be known in order to solve the statics equation. Boring tries to solve the geometry question and to some extent also the question of the material. Can it in fact be done in this way?

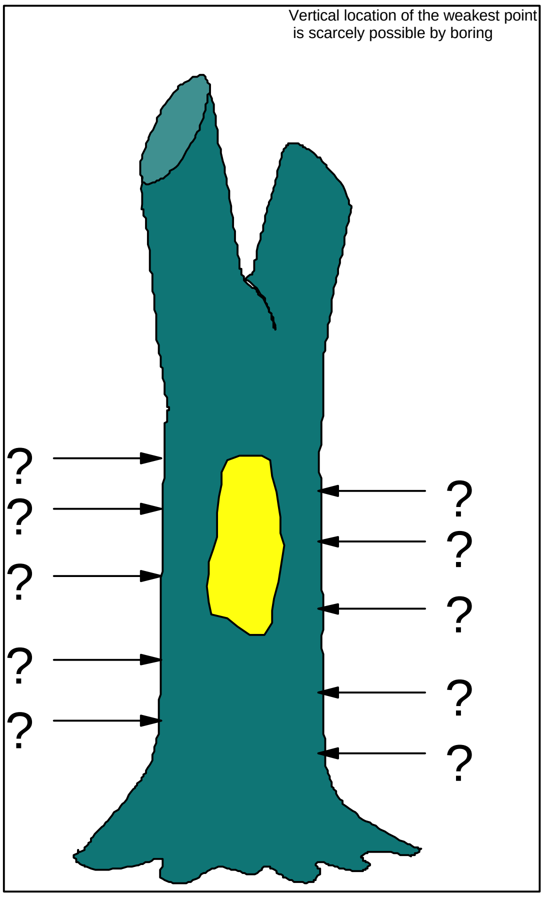

Fig. 20

The weakest cross-section can scarcely be found by boring, especially in the case of hidden cavities.

Problems practically insoluble by boring

Here we shall discuss the five problems which are insoluble by boring.

1. Finding the fracture horizon (Fig. 20)

With stem rots deriving from the root zone, the fracture weak-point lies between level 0 in trees without pronounced root spurs and 0.5 m with large root spurs to about 1.3 m. But a drill of 0.3 cm diameter can be applied in 1.3 m/0.3 cm = 433 successive vertical positions over just the vertical line alone. How does one find the representative boring point?

2. Finding the weakest direction (Figs. 21 and 22)

Let us consider the circumferential direction in the same way. If the old tree has a diameter of 1 m, then there are 314/0.3 = 104 positions for the borer to determine the carrying capacity. That is necessary for just one single load direction) for every fibre bears its share, and must be individually weighted for a computational approach. Numerical evaluation is easy when the stem is sawn through. As every fibre is exposed in situ, the geometric carrying capacity can be calculated with a small graph programme. Accordingly, information on the tree's safety is much greater from a felled cross-section than from boring. As shown in Part 1, the Elastometer achieves the predictive power of the exposed cut surface, as the carrying contributions of all the fibres are concentrated representatively in the peripheral fibres, and the cross-section itself automatically assumes the correct arrangement. Accordingly, with the Elastometer (20 cm long) the positions over the whole measuring height are reduced to 130/20 = 6. With three Elastometers applied at the same time, just one pull and release will suffice for predicting the fracture force in the lower stem.

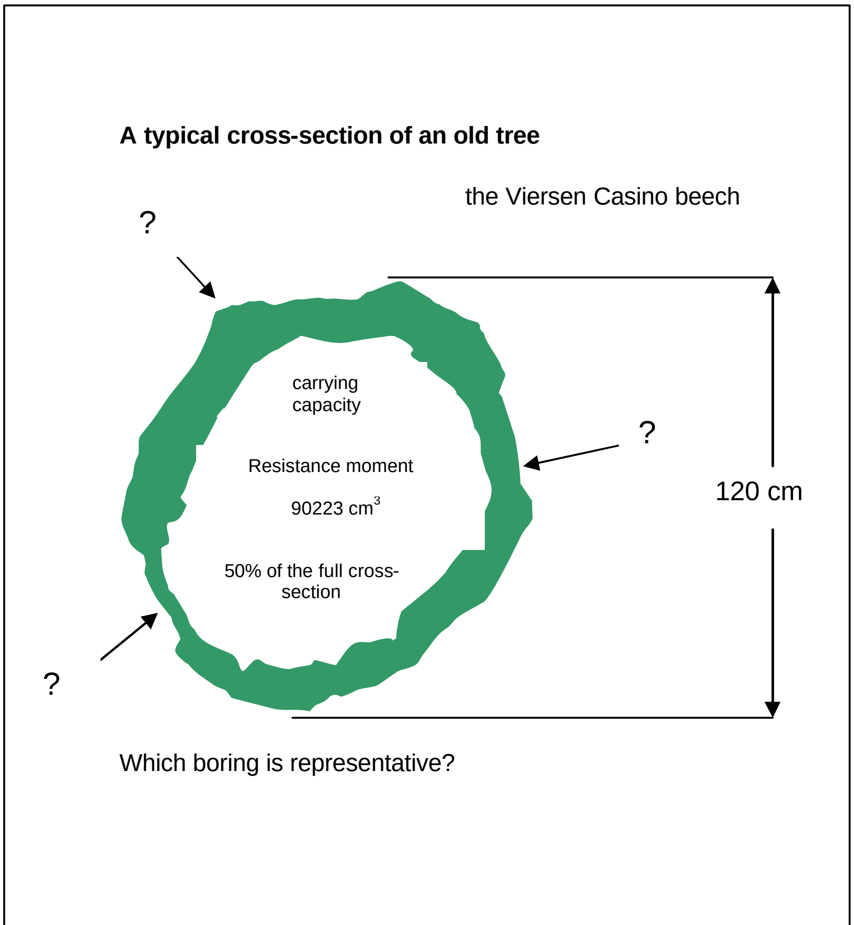

Fig 21

What is the weakest place, or how representative is the place for the whole cross-section?
Every fibre contributes its bit to bearing the load, in accordance with position and load direction. Apart from direct measurement of the representative peripheral fibres with the Elastometer, the geometry of the carrying capacity can only be determined by an accurate evaluation of the cross-section. And this cannot be done by boring. To begin with tree statics, we determined the exterior and interior contour and evaluated it via resistance moment until we used the direct stretching measurement.

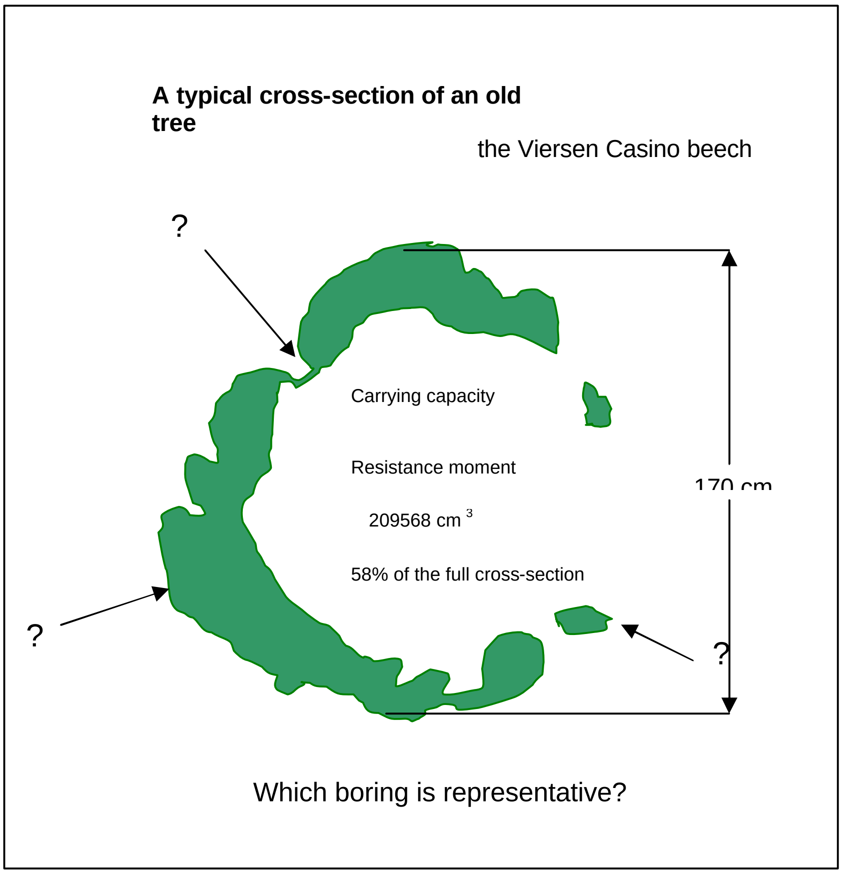

Fig. 22

The cross-section in Fig. 21 and this one come from the same tree. This again highlights the problem of determining the weakest cross-section vertically. The upper cross-section transmits only half the load of the lower one (compare the resistance moments). The reason is the absolute dimensions of the two cross-sections. The upper one has an outer diameter of 120 cm, the lower one 170 cm.

3. Incorporating the borer result into the complete geometry of the critical tree zone (and hence impossibility of converting the spot value into the geometrical carrying capacity of the part of the tree).

To calculate the weak place with computational precision with borings, 433 x 1047 = 453 436 positions would be necessary, though this could be reduced somewhat with experience. Even so, the claim that the **'extent of cavities'** can be determined with a borer (Rinn, 1994, p. 602) is tenable only at the cost of very many borings. However, an approximate extent should never be used in calculating the geometric carrying capacity.

It is easiest to find a uniform wall thickness in oaks, where their supporting tube consists only of sapwood. But the supporting residual-wall thickness of hollow trees, for example in Figs. 21 and 22, is seldom uniform. And as shown above: all the fibres contribute to carrying the load, depending on their position Wall thicknesses ranging from 2 cm to 20 cm thick are found on the same cross-section. Which wall thickness is representative? Which blind boring information is correct? What is to be done if the tree is not circular?

If it is buttressed? **The result from a few boreholes can never be computationally transferred to the carrying capacity of the stem!**

Before the research results of shigo, Liese, Dujesiefken, Reinartz, Schlag, Wiebe and Wessolly become generally used in tree care and in the 1992 ZTV, decayed trees used to be excavated right out to the healthy wood. This also provided an insight into the residual wall thickness. Because of its massive side-effects, this source of information is no longer available to practitioners. But there is no way back, and the missing information cannot be replaced by the borer.

Diagnosticians resorting to boring are conscious of damage to the tree. As little boring as possible should be done, but this is a major conflict of purpose. But with one single boring in one horizon, the geometrical carrying capacity eventually deduced can easily fluctuate by a factor of 10 (for example t = 2 cm and t = 20 cm) that is 1000%. The expert on tree statics relying on the borer will be forced, because of his duty of care, to make many borings to record the carrying situation.

The practitioner may decide to use the smallest wall thickness for determining fracture safety; with greatly differing wall thicknesses this is a 'compensatory defect', but it is not scientifically tenable. It is in no way fair to the supporting substance present in the tree, but it merely suggests a plausible solution. The proponents of this method must

however ask themselves why every tree with an open cavity with t/R = 0 (zero) on the weakest side has not broken off long ago?

4. Determining the tree's fracture load

The fracture load of a tree can be calculated if the geometry of the cross-section and the compression strength of the green wood in the longitudinal direction are known precisely.

As the geometry of the stem cannot be reconstructed from a few borings, likewise it is not possible to calculate the fracture load of the tree from a few borings, even if the material values of the green wood are known.

5. The clear quantitative transferability of radial strengths of a core sample to longitudinal strengths

As the first four points show that the geometry question cannot be solved with borers, should one assume that at least the material question is settled by investigation of a core 5 mm diameter in the radial direction. Anyone who has held a core in his hand knows that it can break apart by itself without any force being applied. Moreover, because of the small dimensions it depends very much on the sharpness of the borer. (As yet, no comparative values are available; it is merely recommended that the borer be sharpened). Then the core is placed in a fracture-test instrument, and is loaded in a way which does not occur in the tree. The annual ring boundaries are loaded in tension. Notch stresses occur at the fixing place (Spatz: open letter to Mattheck, 30 Nov.'93). Consequently the proponents must ask themselves about the transferability of the fracture values, and thus the sense of incorporating them into the fracture-safety calculation. As so-called proof, so far only 2 sample cores are known, in which moreover the transfer values between radial and longitudinal strength vary by a factor of several times. (See AFZ 14/94 in Mattheck, Bethge & Zipse in response to criticism by Lesnino & Glos on the Fractometer in AFZ 8/94).

What does that look like at another place in the tree, or in a tree of the same species but different growth conditions?

If the material strength deemed unnecessary on another occasion (quote Mattheck, Breloer & Bethge, 1994, p. 409: 'The **wall-**thickness/radius **ratio determines the tree breakage, not the tree species')** [author's note: or different wood strengths] should still be of importance,then a catalogue much more comprehensive than the Stuttgart Strength catalogue would need to be compiled. It would have to comprise both the radial strengths and also the values for converting them to longitudinal compression strengths. We still do not know whether this is indeed possible. But what does the research expense matter if the geometry question cannot be solved with borings?

Glos & Lesnino (AFZ 8/1994, p. 417) come to the conclusion:
'In summary it can be determined that the Fractometer values can provide scarcely any conclusions on the fracture safety of whole stems, because (1) the strength values are determined in the radial and not in the longitudinal direction, (2) these values have only limited local predictive power, and (3) these values also exhibit a large scatter'.

Schwarze & Fink (1994, p. 192) state that **'no matter how important experience from purely practical use of commercial diagnostic instruments** [author's note: Resistograph, Fractometer, Impulse-hammer] **may be for their evaluation, they do partially reflect circumstances which are not objectively reproducible'.**

Liability when using commercial instruments Elfgang (1993) adds:
'In exceptional cases ... diagnostic instrumental aids can support expert assessment. But be careful - such instruments can replace neither the necessary knowledge nor the necessary experience of the expert. Before using them their functional safety and usefulness, and the probability of wrong diagnosis must be checked. It is not possible to transfer expert human work involving liability to instruments which are free of liability. In the case of non-unavoidable failure,'such instruments, it is right to presume that the duty of ensuring traffic safety has not been adequately taken into account'.

As already quoted above, Mattheck, Breloer & Bethge (1994, p. 409) correctly state that, of the bearing components of the statics triangle, only the geometry counts (for the compression strength differences between the tree species are small). Quote: **'The wall-thickness/radius ratio determines the tree breakage, not the tree species' [author's** note or different wood strengths]. Why then does one need a radial fracture instrument for the sound wood if the wood strength is not really important? Without complete geometry of the cross-section, the measured value cannot be converted anyway.

Obviously the instrument is helpful in identifying one special fungus which strikingly separates stiffness and strength, viz. Hypoxylon deustum. First, however, the tree must be identified, and this is sheerly impossible, as the fungus provokes no symptoms. Should boring be done on suspicion? But after identification of the fungus in the early stage (which is unimportant as regards statics), the predictive value does not extend beyond the point sample. If the tree's statics situation is critical because of H. deustum, it will appear between the root spurs with its admittedly insignificant fruit bodies, and then one will no longer need to determine it by a fracture sample.

And as shown in Part 1 on SIM, weakening of the statics by Hypoxylon deustum can be identified blind with the Elastometer.

On residual wall thickness

Statistics showing that below a given wall thickness there is an increased frequency of failure may be trite, but are not fair to the individual tree. If one considers the geometric carrying capacity of a ring, it exhibits the same picture without statistics. Below a wall thickness of one-third of the radius, there is a decrease of only 25% compared to the full cross-section (Fig. 9 in Part 1). Old trees with safety values of far over 400% can be so over-dimensioned that the loss of 25% definitely does not matter. The old released beech trees in Table 2 show a basic safety of the full crosssection of up to 1200% against a wind of force 12. A tree with a mean wall thickness of t/R = 0.3 still has a safety of over 300% to 800%. One often finds old oak trees which have been standing for decades on only their sapwood.

Nr.	Tree height	Stem girth at 1.2 m	Crown area	Gale stabilty	Gale fracture safety	Residual carrying capacity	Mean wall thickness	Wall thickness to Radius	Fracture safety % full
	m	cm	sqm	%	%	%	cm	t/R	rounded
1	23	610	360	160	375	31	10	0,1	1.200
2	22	462	282	230	385	45	10	0,13	860
3	28	499	448	200	170	45	11	0,14	380
4	18	300	222	110	260	54	7	0,14	480
5	25	460	303	200	155	38	9	0,12	410
6	30	610	474	160	130	23	6	0,06	570
7	28	452	497	160	145	49	11	0,15	300
8	28	464	279	150	264	55	10	0,14	480
9	21	430	284	250	500	43	10	0,15	1.160
10	26	531	614	160	187	32	8	0,1	580
11	26	440	237	190	240	53	11	0,16	450
12	25	440	303	200	190	59	12	0,1	320
13	16	367	185	250			30		
14	25	339	334	100					
15	24	425	326	150	120	33	7	0,1	540
16	21	500	280	200	440	46	11	0,14	950
17	19,5	371	243	200	330	32	6	0,1	590
18	21	382	264	190	275	55	10	0,18	530

It is by no means correct to allow a tree only a reduction of 25% in its carrying ability. With partial cavities and non-symmetrical decay, the reduction is much smaller.

The important thing is:

How much cross-section does the tree absolutely need? With crown intervention, the 'nature monuments' evaluated in Table 2 would always be clearly below the 0.3 t/R limit. Nevertheless they have been standing safely for decades. If the 0.3 limit is useful for anything, then it is that under some circumstances up to that point no-one needs worry about a cavity. But only under certain circumstances, for there are also solid healthy trees which are vulnerable to fracture, as a summer storm in Heilbronn has shown.

The point frequency diagram of broken trees in Mattheck's publication shows a distribution over a very wide range: the fracture values of the trees lie at t/R between 0.32 and 0.08 (factor 4). Besides the beech trees listed in the above Table, we have found fully crowned trees which had much lower values and were still sufficiently safe. The extreme values in our observations were hollow oaks which were fully crowned and had stem diameters up to 1.6 m, still standing on their sapwood of only 4-5 cm. This is t/R = 0.055.

On one hollow elm 24 m high and 70 cm stem diameter, after a control fracture test we measured a supporting wall thickness of 2 cm; again that is t/R = 0.057. To break it required a load of 3.5 t at a height of 17 m. It would still have been safe in the hurricane.

These results show that tree statics must be approached with great precision.

Another concrete example:

If we assume that a constant wall thickness exists, the residual cross-section would be a circular ring, which virtually never occurs. Examine the two cross-sections in Fig. 23. Both can carry the same load in bending, and come from trees of identical crown size. The only thing different in a possible fracture is the fracture pattern, not the load height on

attaining the elastic limit. What now? One could admittedly say that the carrying capacity of the hollow stem has decreased to 60% compared to the full stem, but the most important reference is missing, namely knowledge of the basic statics substance. A visual assessment of the sail area is not enough. With identical crown area but different crown form the wind pressure can differ by 20% to 100%.

To sum up:

Whatever the situation, it is clear that in conscientious fracture-safety analysis, the exact crown sail size and the wind load must definitely be determined. We have found that the stable cw value above wind strength 10 in trees in leaf is a maximum of 0.35 (horse chestnut); 0.25 can be set as a working value for a normal broadleaved tree. The maximum estimation error of the cw value of about 30% between 0.25 and 0.35 is much less than the great range of the hurricane loading, which can be up to 800% (Part 1, Fig. 13). But in any case with cw = 0.3 one will be on the safe side.
For how much time does a vigorous tree have with t/R between 0.32 and 0.08? All experience shows that it can be decades, depending on the tree species.

Comparison of the carrying capacity of stem diameters under bending load

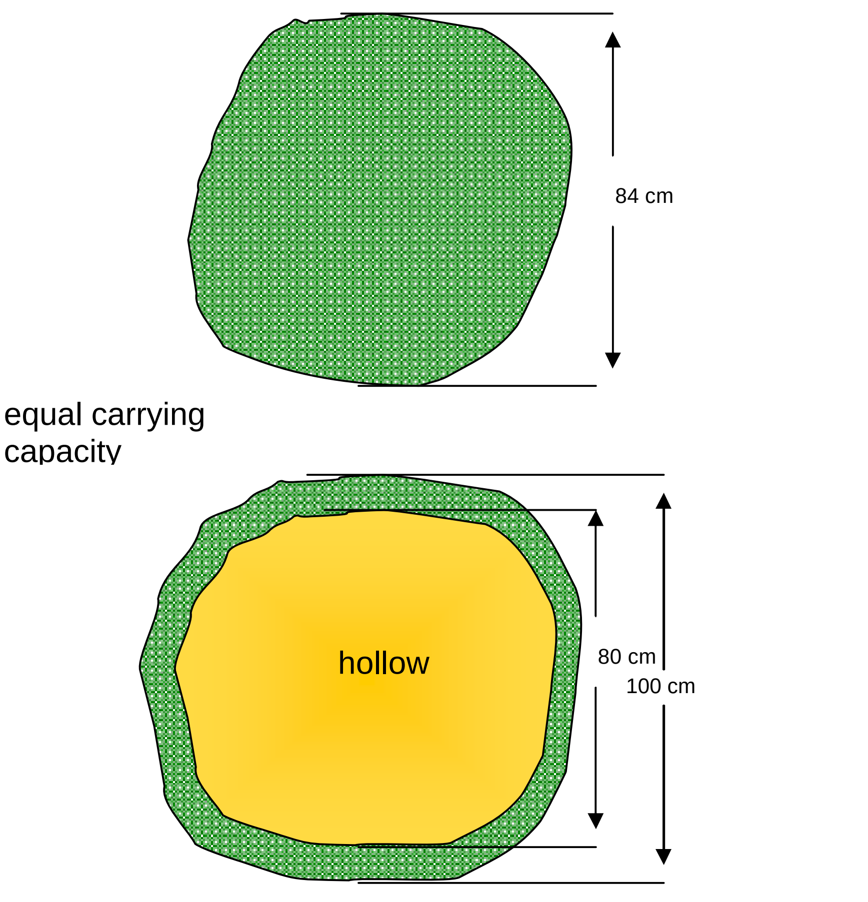

Fig. 23
Both cross-sections are carrying the same amount and should well come from the same tree. The important thing is not the hollow cavity but the load in the crown, and this may differ considerably with the stem diameter.This si shown in Figs, 11,12 and 13 (Part 1). Spatz has also shown that the elastic limit (primary failure) is equally valid for both cross-sections, so the Elastometer method does work. The only difference is the fracture pattern (secondary failure) which is unimportant for the safety forecast.

The boring methods lack the statics

Boring lacks a linkage to the hurricane force acting on the tree, and the wind load cannot be measured off on the stem cross-section, because the stem cross-section depends not only on the mechanical stimulus but rather more on the competition situation, nutrition, nutrient availability and the species, i.e. on the biology. If mechanical stimulus were the important thing, then forest beech or spruce trees would have to have thicker stems than solitary trees, as they are most stimulated and moved by oscillations. However, that cannot be confirmed in the latest scientific studies. Here too it is seen that the self-measuring theory is the inadmissibly generalized deduction from a trend, and cannot replace an expert evaluation. The so-called self-measuring theory of Mattheck presumes that the tree conditions itself in an optimum way, so that only the damage needs to be evaluated. But this is clearly contradicted by the evaluation of the 1366 expert tree assessments. Admittedly there is a trend for stressdifferences to even out or to decrease, but no more than that. The tree is not obliged to fulfil it.

Summary

A borer cannot reproduce what happens in the tree during a hurricane.
The borer cannot even settle the geometry question. Strictly speaking, it is merely a probe with much too much room for interpretation.
Boring provides only absolutely inadequate spot insights. The fracture sample of the increment core does not alter either. Accordingly it will never be possible to convert it to the whole statics situation, even though perhaps one day we might succeed in converting radial strengths to longitudinal strengths. Even the much discussed t/R = 0.3 limit is unsuitable for expert tree diagnosis, for there definitely are unpruned free-standing trees which are still standing safely below 0.1. The reason is the wide range of possible tree loading, wbich according to the latest scientific studies may amount to a factor of 8 at the same stem diameter. The thing is to use this range to the benefit of the trees, but to do this we urgently need to analyze the load exerted by the wind on the crown as accurately as possible.
On the basis of international research results over the last ten years, the **ZTV Tree Care** (1992) expressly points out that wherever possible injury-free methods gentle on the tree should be used in tree diagnosis. Accordingly, the use of injurious instruments culminating in the Endoscope are contrary to the sense and purpose of the **ZTV Tree Care.**
Diagnostic methods which mix visual with numerical elements for decision-making do not provide for reproducibility.
In determining safety by the VTA method, some values are measured and others, for example the most important value, the tree crown, are only estimated visually. Then everything is inextricably mixed together for the decision-making.

Mutual weighting and results are not reproducible for a third party (see also Schwarze & Fink, 1994: **'they do not objectively reflect reproducible circumstances').** This approach would be feasible only with fixed identical loading limits for all the trees. But these do not exist. In contrast the point frequency diagram for broken hollow trees shows a scatter around the factor 4, and thus is not suitable as a firm reference value. Moreover, confirmation has never been found for a generalized safety value for all trees of 4.5; on the contrary, a scatter around the factor 8 was found. The same also applies to the self-measuring theory which states that the tree itself can best measure its own loading and put on the increment needed. This is only a trend, and then exclusively for the permanent loading direction. It has nowhere been proved that a short-term hurricane loading could trigger a lasting growth stimulus. The scatter factor 8 from 980 trees evaluated also does not allow this conclusion. This means that no fixed pattern can be deduced for the safety analysis from a tendency or susceptibility. Spatz (1993, see above): a **merely qualitative statement is not falsifiable and therefore not capable of verification.**

Accordingly, the comparison proposed by the FLL between visual methods supported by boring and the Elastometer method could not be successful for the former, and was therefore avoided.
Individual elements of the visual methods can provide valuable indications, but development of symptoms says nothing about the statics. A symptom clearly displayed by the tree may show that the damage has been rectified and has no effect.
In contrast, the Elastometer method, as shown in Part 1, is thoroughly quantified, clear and therefore reproducible in determining the fracture load. It is correctly based on German Standard DIN 1055 for the designing of structures, complemented and refined by our own wind-load research in Special Research Field 230 of Stuttgart and Tuebingen universities. In giving the safety value, only the wind resistance cw is estimated to begin with. In this way the estimation error is well below the range of possible crown areas or wind loads.
The SIA method explained in Part 2 is freely available for the practitioner. It is based on many years of measurements with the Elastometer and experience in the aerodynamics of trees. It is the necessary consequence of the fact that the range of wind-load variation is by far the most important factor in tree assessment. Therefore the basic statics substance must be determined first, and then any statics damage is related to this. This definitely requires a re-think in traditional tree diagnosis. Time is incorporated by adding the vitality element.

SIM are the only currently available methods for monitoring trees which can (without injury) provide reproducible and comprehensive values relevant to the tree's safety condition. Bore cores do not get anywhere near to this.

Literature

Amtmann, R. (1986). (Dynamic wind loading of conifers). Schriftenreihe Forstw. Fak. Univ. Minden, 74.
Davenport, A.G. (1960): Rationale for Determining Design Wind Velocities. Journal of the structural Division. Proc. ASCE v. 1986.
Davenport, A.G. (1965): The relationship of Wind structure to Wind loading. Wind effects of building and structures. V. 1, HMSO, London.
Elfgang, A. (1983). (The duty of traffic safety): Practical seminar, Institute for Tree Diagnosis.
Fritz, W. & L. Wessolly (1973). (Aerodynamics of buildings -wind-tunnel studies on model buildings). Diploma, Inst. Aerodynamik. Univ. Stuttgart.
Hirtz, H. (1981). (Progress report on work on rules to record wind effect on structures). Konstruktiver Ingenieurbau, Rep. No. 35/36 Bochum.
Hirtz, H. (1978). (Report on work of the DIN 1055 Part 4 committee in the Building Standards Committee of DIN. Aeroelastic problems outside air and space flight). Mitt. Curt-Risch-Inst., Hannover.
Höster, H.R. (1993). (Tree care and tree protection). Stuttgart.
Ishizaki, H. and I.W. Sung (1971). Influence of adjacent buildings to wind. Wind effects of Buildings and Structures, Tokyo, 5. 145.
Kamei, I and E. Maruta (1979) Study on Wind environmental problems caused around Buildings in Japan. Journal of Industrial Aerodynamics 4, 5. 307.
Kollmann, F. (1951). (Technology of wood and wood-based materials). Vol. 1. Berlin.
Kusche, D. & M. Siewniak (1994). (Tree care today). 3rd edition.

Lesino, C & P. Cbs (1994).(The Fractometer) AFZ 8, p. 417.
Mattheck, C., I.K. Bethge & H. Breloer (1994). (General validity of the rules for evaluating risk trees). Gartenamt, 43 (6), p. 407.
Mayer, H. (Wind and tree oscillations). Wiss. Mitt. Meteorol. Inst. Univ. München. No. 35, p. 66.
Mayhead, G.J. (1973): Some drag coefficients for British forest trees derived from wind tunnel studies. Agric. Meteorol. 12, 5. 123.
Melbourne, W.H. and P.N. Joubert (1971): Problems of Wind flow at the base of tall buildings. Wind effects of Buildings and Structures. Tokyo. 5. 105.
Murakami, S.K., Uehara and H. Komine (1979): Amplification of wind speed at ground level due to construction of highrise building in urban area. Journal of Industrial Aerodynamics 4, 5. 343.
Rinn, F. (1994). (Tree testing - illustrative, qualified and gentle). Neue Landschaft 8, p. 598.
Rinn, F. (1993). (Models for assessing the fracture safety of trees). Landschaftsarchitektur, 4, p. 55.
Ruschweyh, H. (1982). (Dybamic wind effect on structures). 2 vols. Berlin.
Schlaich, J. (1966). (The effect of wind gusts on structures). Bauingenieur, 41, p. 102.
Shigo, A., K. Vollbrecht and N. Hvass (1985). (Biology of trees and tree care. A photo textbook).
Schwarze, F. & S. Fink (1994). (Determination of wood decay in living trees). Neue Landschaft 3, p. 192.
Wessolly, L. (1988). (Loads on trees caused by the wind). 11th Bad Godesberg Tree Seminar.
Wessolly, L. (1992). (Material and structure properties of trees. Continuation of the Stuttgart Strength Catalogue). Conference volume, 15th Bad Godesberg Tree Seminar.
Wessolly, L. (1994). Neue Landschaft, 10. (Root damage and stability of trees).
Wessolly, L. (1993). (Stability and fracture safety of trees). Gartenamt 42, 8, p. 486.
Wiebe, S. (1992). (Wound development and wound treatment on trees with special reference to wood moisture content). Diss. Univ. München.
Zuranski, j. (1966). (Wind loadings on buildings and structures); Cologne.