Assessment of hazardous trees

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Introduction
Trees are an essential, perhaps dominating, part of the plant infrastructure in any urban environment. Visually they are the substance about which a city's green space is arranged. Their size, and their height and volume, give the natural landscapes of our towns the 'third dimension', linking earth and sky. Psychologically and emotionally they serve as a link with our past, ground the present, and promise a future. I believe that trees invade our subconscious – they cannot be overlooked; from the cherry tree we climbed as a child, to a kauri planted by a loved grandparent, trees planted to commemorate the death of a loved one, or on the birth of a child, all serve to link our lives with the environment.

All this serves to establish an emotional bond with trees that become manifest in the daily lives of those managing the urban forest. Local authority parks officers and arborists will tell you of the seemingly endless tree issues that drive apparently normal and sane people to the brink of madness. I have worked for many years as a council arborist, and was daily subjected to that dreadful phrase "I love trees but…". You knew straight away that this good citizen wanted their particular tree removed, but were uncomfortable with their request. Why is it unacceptable to say "I hate trees"? I am certain that I have met people who do hate them, but who would never express that view in public.

Communities respond quickly and passionately to issues of tree removal, and yet are equally engaged when a large street tree collapses and damages their fence or car. So what are our obligations in maintaining this urban forest? It certainly cannot be left unmanaged and we have to balance the emotional response of our community with the practical requirements of the trees. While nobody reading need be reminded that trees are living things, you would be surprised what the general populace may think.

So, our obligations then – as an arborist I am concerned primarily with one – to ensure that the trees in the urban forest are safe. This paper examines how, indeed if, this can be achieved. Are there hazardous trees out there, how do you recognize them, how you assess the degree of hazard, and how often do you inspect these trees?

Trees safety factor
The question here is can absolute safety be guaranteed? For many years the pressure of hazard tree assessment was to state, categorically, that a given tree was 'safe'. This is clearly an unrealistic position to take, and incidentally one not expected of our artificial environment, so how can it be demanded of our natural one?

In an engineering sense a safety factor of 1:10 is considered the norm for manufactured structures. A safety factor is determined by:

$$S = \frac{\text{breaking stress of the material}}{\text{working stress}}$$

What would you expect from the natural world? Until Mattheck (1991) undertook his research at the Karlsruhe Institute of Technology (KIT) in Germany it was (strangely) assumed that the safety factor in trees was 1:1.5. That is that trees failed just above

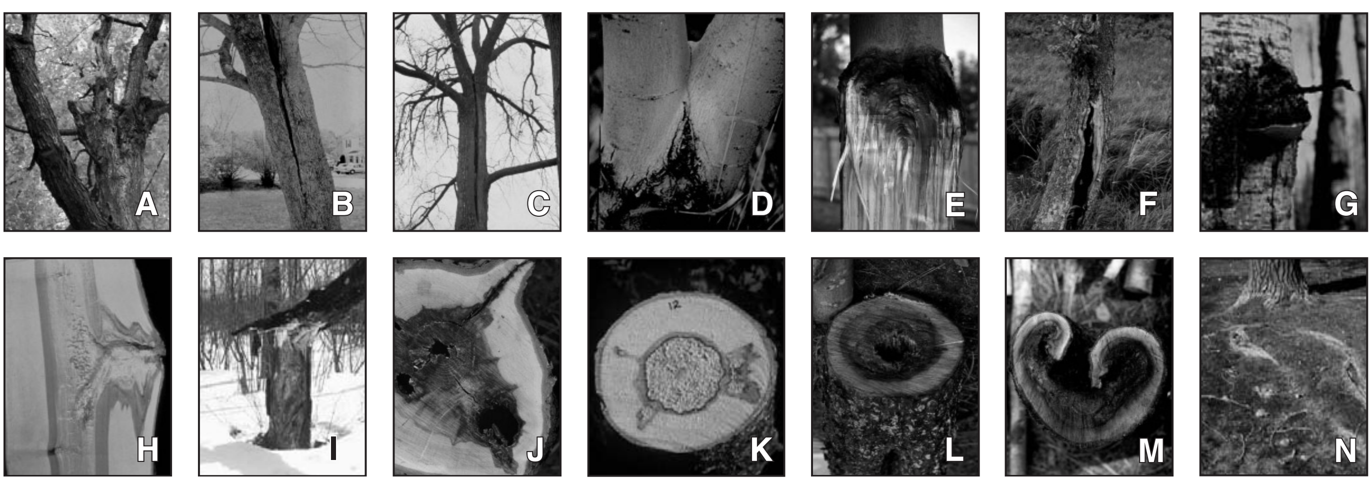

Fig. 1 Examples of tree faults. **A,** tree with dead top. **B,** leaning tree with a large vertical crack. **C,** weak union leading to large crack and decay. **D,** close-up of a weak union. **E,** weak union leading to structural failure. **F,** open cavity caused by cracks and decay. **G,** canker. **H,** decay beneath the canker. **I,** canker decay causing collapse of tree. **J,** cross section showing multiple cracks. **K,** internal decay. **L,** internal decay leading to cavity. **M,** 'rams horns' caused by growth after wounding. **N,** root decay.

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normal loading ('loading' in this sense refers to the forces the tree is subjected to, such as wind and gravity; see Cullen, 2002). In fact Mattheck found that trees operate within a safety factor of at least 4.5, i.e., they can tolerate loads at 4.5 times the normal. However, this of course means that they may fail when external loads exceed this safety factor, and that no tree can be deemed to be absolutely safe.

European courts have long recognised this fact, and a ruling in the Supreme Federal Court in Germany in 1965 stated:

> "A street tree can certainly not be required to be absolutely free of imperfections and dangers. It is simply not possible to achieve such a state of affairs."

Figure 1 (A–N) illustrates the various tree faults that need to be assessed.

Biomechanical assessment

Having accepted that even the finest of trees may fail under exceptional circumstances does not give the arborist an 'out clause' for all hazard tree assessments. What needs to be established is whether there are predictable failures that occur. Mattheck developed the biomechanical assessment criteria that are the basis for modern hazard tree evaluation (Mattheck and Breloer, 1994).

The arborists' initial response was that this cannot be done; you cannot apply some mathematical formulae to the assessment of a tree. And perhaps that is true. Formulae in themselves are not the final say in the condition of a tree, but are an essential element of hazard evaluation.

In this paper, I examine one area of biomechanical assessment, probably the most commonly applied, that is, how to determine the structural integrity of a tree with an internal cavity. This is the 'Wood Strength Loss Ratio' formulae of t/R. It is applied on an enclosed concentric cavity in the trunk of a tree, i.e.,

> $t/R>0.30$, where t is the thinnest measurement of sound wall, and R is the radius at that point.

The t/R ratio needs to be equal to or exceed 0.30, or the tree fails this structural assessment (Fig. 2).

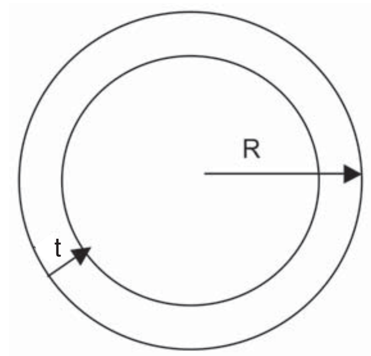

Fig. 2 Wood strength : loss ratio of a concentric hollow cylinder. t is the width of the sound wall, R is the radius; t must exceed 30% of R.

This does not necessarily mean that the tree is automatically condemned, nor does it tell you that the tree will fail at 12.30 pm next Thursday! It is a value below which the tree's safety factor is reduced to about one, in other words, it will fail under normal conditions. A theoretical model was developed from experimental studies and computer simulations and measured against actual events in the field. In field studies the 0.30 threshold was found to have 94% accuracy.

However, not all trunk cavities are either enclosed or concentric, so other tests need to be employed.

Where the cavity has a single open face, that face must not exceed 33% of the total circumference of the tree (i.e., the 'Angle of Opening' shall not exceed 120 degrees – Fig. 3). Where there are multiple cavity openings, the sum of those faces must not exceed 50% of the total circumference (Fig. 4), and t must exceed 50% of the radius.

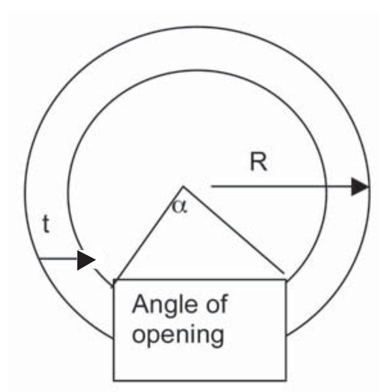

Fig. 3 Single cavity opening. α should not exceed 120 degrees (30% of trunk circumference); t must exceed 30% of the trunk radius.

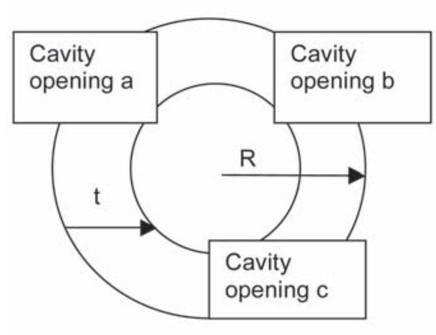

Fig. 4 Multiple cavity openings. Sum of a + b + c must not exceed 50% of the total circumference; t must exceed 50% of the radius.

On an eccentric cavity (i.e., one that is not central to the trunk cylinder) the t/R formula is applied, provided the cavity radius exceeds 50% of the trunk radius at that point (Fig. 5).

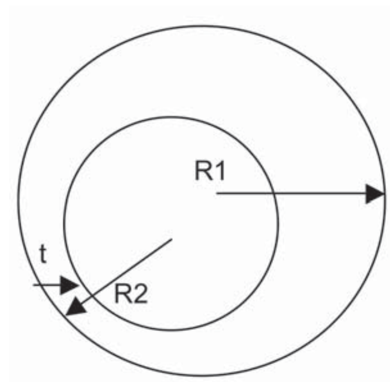

Fig. 5 Eccentrically placed cavity. t/R formula is applied only if R2 exceeds 50% of R1.

These tests are all well known and relatively easy to apply. What is not easy to uncover however is the exact thickness of the intact trunk wall (t). This required the development of a range of sophisticated (and expensive) investigative tools and technologies, ranging from the Sibert and Resistograph 'smart drills', to the sonic and ultrasonic devices such as the Metriguard Stress Wave Timer (Fig. 6A–B) and the Picus Tomograph.

Have these 'tests' added to the field of hazard tree analysis? My answer is a resounding "yes". Have they given the definitive criteria for assessing the structural integrity of a tree? My answer is a resounding "hmm…".

Prior to the development of these biomechanical assessment criteria, the arborist had to rely on opinion, experience, and species profiles (which could be wildly inconsistent). There are now well accepted empirical criteria to base ones assessments on (Mattheck and Bethge, 2000). The arborist is however, not yet made redundant. The failing of any criteria does not automatically condemn the tree to the axe, and a myriad of other factors need to be considered before the final decision is made.

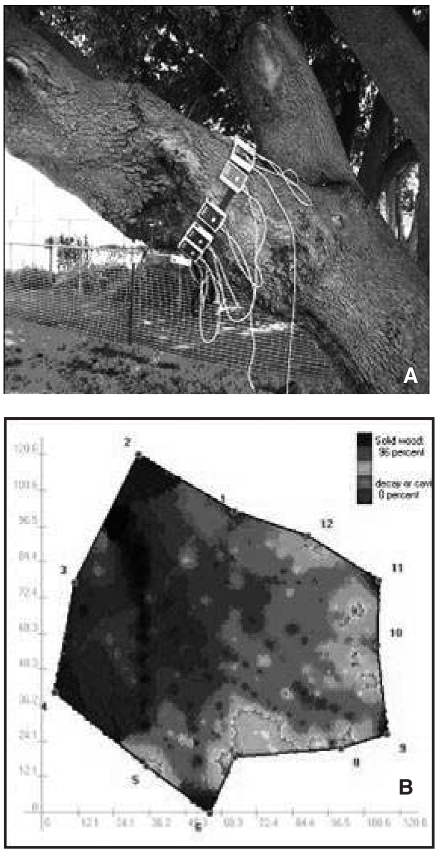

Fig. 6 Stress Wave Timer. **A,** transponders attached to a branch. Transponders send out the sonic pulse to determine the internal condition of the wood. **B,** computer image of a trunk in cross section.

I find it odd that one of the criticisms of Mattheck's biomechanical formulae is that they 'condemn' trees that have decay. This is simply not so – they may say "this tree does not pass this threshold", but they do not say "so lets cut it down". I am old enough to remember a time when any decay signalled a trees doom. What Mattheck has done is to say "some decay is acceptable, but this much is too much". This is a great advantage in hazard tree assessment and has in my opinion saved many a tree from overly cautious arborists making 'safe' judgements and condemning trees that possessed non-critical amounts of decay.

Furthermore, by establishing a 'minimum standard' it has ensured that trees that are dangerous are either removed or remedially pruned. In other words, unsafe trees can now be recognised and managed. There is no greater threat to the urban forest than allowing unsafe trees to remain untended, for their eventual collapse (often causing damage) results in the removal of sound neighbouring trees in a knee-jerk reaction to public opprobrium.

Visual Tree Assessment

Assessing the 'likelihood of failure' is but one step in the hazard tree assessment process, and the initial investigative procedure is known as Visual Tree Assessment (VTA), a process also developed by Claus Mattheck. This process includes both the biological and mechanical assessment of the tree, although this paper focuses on the mechanical assessment criteria. VTA is mainly concerned with the 'extraordinary' or abnormal characteristics of the tree being assessed. "The body language of trees" (a term coined by Mattheck) describes how a tree attempts to restore a state of uniform stress about its surface by adding extra material (wood) at points of high stress loading.

This results in a recognisable range of defect symptoms (ribs, bulges, swellings, etc.) that signal where further investigative work is required. If that defect is confirmed then it should be measured, analysed and assessed/evaluated against the appropriate biomechanical criteria.

Another question often asked is – how often should this VTA / tree inspection process be undertaken? The norm is once every two years for mature trees, although a large senescent street tree may require two visits a year (if it is a deciduous tree, then once in leaf and once when the branches are bare). Young, semi-mature trees may not require visits more than once every five years. However the frequency of tree inspections depends entirely on the condition of the tree, its location, and the amount of traffic beneath. It is also prudent to inspect your tree population after a significant storm event, or an unusual weather condition (for example, strong winds from an unexpected direction).

Hazard evaluation

The predictability of failure is one aspect of hazard tree assessment, but complete risk assessment must also consider the target (be it a house or a public street), and the duration of occupation of that target (from a residential dwelling possibly occupied for 24 hours a day, to a seasonal picnic area that may only be occupied for a few hours a day over summer). This appears to me too much to ask of the poor arborist assessor alone, who should restrict their assessment to the likelihood, or probability, of tree failure occurring. The assessment of the target and risk may be better shared between arborist, environmental officers, parks managers, or risk assessors. I have seen some 'risk assessment' criteria based on a 'political embarrassment' threshold; where a subsequent single death is rated as 'embarrassing', and a multiple fatality of 20 or more, considered 'extremely embarrassing'.

As an arborist, such an overt political assessment has a great deal of appeal. However, I have yet to see a satisfactory tree hazard evaluation system that incorporates all aspects of site, tree, and target into a definitive and meaningful rating.

Fig. 7 Tall heritage tree showing the potential risk to an adjacent building.

This paper concentrates on the tree assessment section of hazard tree evaluation, but a dangerous tree with a high probability of failure in a forest would not be considered as hazardous as the same tree would be in an urban location (e.g., Fig. 7), just as an unsafe sapling rates as less of a hazard than a large mature tree. So while arboriculture may be getting better at assessing the condition of a tree and identifying failure thresholds, there is still much work to be done in judging the significance of the threat the tree poses.

Nor is it necessary to remove all trees that represent a hazard – trees can be cabled, propped and pruned to alleviate the hazard, or the target can be removed or isolated from the tree. How many children's playgrounds have been built under the shade of a significant tree in a park, only to result in the trees' removal when a branch breaks during a storm?

On a final note the European Court may well have a lesson for us all in its judgement:

> "Not every falling branch or collapsing tree leads to those responsible for civic safety being held liable. Indeed, damage caused by trees can be in certain cases seen as part of the general risk inherent in life."

References and further reading

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Web pages

USDA Forest Service: Hazard Tree home page: http://na.fs.fed.us/fhp/hazard_tree/

Rob Graham has spent the last 30 years involved in many aspects of horticulture and arboriculture. He is currently the principle tutor in the Diploma in Arboriculture programme at Wintec, where he has been for the past 10 years. Prior to that he has worked (in descending order) as an arboricultural consultant, tree company manager, council 'Tree Officer', arborist, and general horticultural 'dogs-body'. Rob has worked throughout Europe and Australasia as an arborist, and been called as an expert witness in numerous court cases regarding the assessment of hazardous trees.

Rob has a BA (Auckland University), NDH, CTS (Merrist Wood), and is a qualified teacher. His obsession is trees.