COMPARING FORMULAE THAT ASSESS STRENGTH LOSS DUE TO DECAY IN TREES

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Abstract. Hazard trees are a concern for anyone who manages trees in a landscape setting, including arborists, urban foresters, and grounds managers. Through research, experience, observation, and common sense, arborists and urban foresters have identified many risk factors that predispose trees to failure. They have also developed thresholds to help determine the degree of hazard and whether a tree is in imminent danger of failing or needs annual (or more frequent) inspections. Two critical factors are involved in strength loss assessment in tree stems with defects. First, it is important to know how much strength is lost due to a defect such as a hollow or cavity. Second, the load required to cause failure needs to be considered since the wood of some trees is inherently stronger than others. Research currently underway at the University of Massachusetts, U.S., intends to test the strength loss due to decay in tree stems. Eventually, once the methodology has been refined, other tree structural defects will also be tested. A need for such research exists because hazard trees pose an important liability issue and because relatively little quantitative testing has been done to establish thresholds to classify trees as hazardous.

Key Words. Hazard tree; strength loss; decay; stress.

Hazard trees are a concern for anyone who manages trees in a landscape setting, including arborists, urban foresters, and grounds maintainers. Considerable time and effort has been spent addressing the problem. Because trees are living organisms, growing in varied environments, it is impossible to predict exactly when a tree will fail. Indeed, tree failures are frequently referred to as "acts of God." Arborists, urban foresters, and others concerned with hazard tree management realize this fact and know that the best way to manage a hazard tree is to assess risk factors of the tree and its target. Armed with that information, they then estimate the likelihood of tree failure and damage potential associated with the failure. Through research, experience, observation, and common sense, arborists and urban foresters have identified many risk factors that predispose trees to failure. They have also developed thresholds to help determine the degree of hazard and whether a tree is in imminent danger of failing or needs annual inspections.

Many of the thresholds, however, are accepted conventions based solely on observation and have little quantitative data to support them. A review of the literature finds guidelines for hazard tree evaluation on which most publications agree; from where the guidelines arise is difficult to trace. For example, many publications cite Wagener's 1963 study as a source for determining strength loss from stem decay (Mills and Russel 1981; Lucas et al. 1984; Robbins 1986; Albers and Hayes 1993; Smiley and Fraedrich 1993; Matheny and Clark 1994; Kennard et al. 1996), but Wagener's findings were based on observation, not experimentation. Other formulae exist to quantify strength loss from decay in tree stems. Like Wagener's formula, they can be traced to mechanics of solids formulae used by engineers to quantify the strength of pipes. Two critical factors are involved in strength loss assessment in tree stems with defects. First, it is important to know how much strength is lost due to a defect such as a hollow or cavity. Second, the load required to cause failure needs to be considered since the wood of some trees is inherently stronger than others.

Research currently underway at the University of Massachusetts, U.S., intends to test the strength loss due to decay in tree stems. Eventually, once the methodology has been refined, other tree structural defects will also be tested. A need for such research exists because hazard trees pose an important liability issue and because relatively little quantitative testing has been done to establish thresholds to classify trees as hazardous. Trees are individuals, possessing a complex, dynamic living system. In order to assess hazard potential—the likelihood that a tree will fail—structural defects must be addressed on an individual basis to provide quantitative data. Ultimately, experimental data could be incorporated into a comprehensive model, standardizing, to the degree possible, hazard tree assessment. Such a model would help hazard tree managers decide when a tree should be removed because of its hazard potential.

This paper describes the various formulae used to determine strength loss due to decay in tree stems, addressing their benefits and shortcomings. After tracing the origins of the strength loss formulae from engineering concepts, the paper then reviews the difficulties involved in applying mechanics of solids formulae to living trees. This paper intends to highlight the need for consistency of hazard tree assessment among arborists. It is important to remember that hazard tree assessment will continue to be addressed on a tree-by-tree basis. Because trees are individuals, it is impossible to create a "one size fits all" management plan to deal with hazard tree assessment.

STRENGTH LOSS FORMULAE

Strength loss from wood decay must be considered along with thresholds that have been established to define when a tree becomes a hazard. An arborist assessing a tree hazard needs to estimate how likely a tree is to fail. Knowing how much strength remains in the defective element (root, stem, or branch) lends an idea of how close is the tree to failing. There are four formulae currently used to estimate strength loss from decay in a stem. Each formula has associated thresholds designed to alert hazard tree managers to the potential for failure. The strength loss calculations and hazard tree thresholds are presented (Figures 1 and 2). The author of each formula cautions that the distinction between a hazard tree that needs to be removed and a nonhazard tree that can remain standing is not clear and rigid. Many factors must be weighed, as indicated by various hazard tree assessment forms (Robbins 1986; Albers and Hayes 1993; Matheny and Clark 1994). Hazard tree assessment is an art as much as it is a science, and both experience and analysis can lend insight into the process. Due to the complexity of hazard tree assessment, it is impossible to predict all tree failures. It is better to approach hazard tree assessment as risk management, in that arborists strive to reduce the risk of catastrophic tree failure.

Most references cite Wagener's 1963 study, in which the author suggested that strength loss caused by decay in conifers followed the formula $d^3 \div D^3$, where d is the diameter of the decay column and D is the average stem diameter inside bark (Wagener 1963). For example, if a 10-in. diameter tree has a column of decay 8 in. in diameter, the strength loss equals $8^3 \div 10^3 = 0.51$ (multiply by 100 to obtain a percentage), for a 51% strength loss. Wagener adapted the formula for strength loss in a cylinder from mechanics of solids and made it more conservative to apply to living trees. In mechanics of solids, the second moment of area, or moment of inertia, of

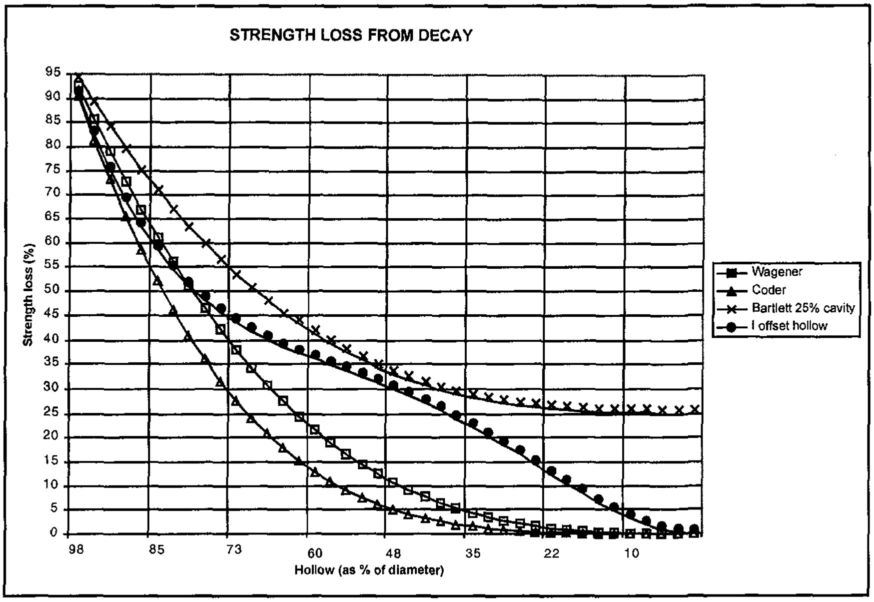

Figure 1. Graph of strength loss as a function of stem hollow percentage. Curves represent different formulae and reflect the parabolic relationship between strength loss and hollow percent: strength loss is small until the hollow becomes large. "I offset hollow" curve reflects the percent loss in moment of inertia for a cylinder with an asymmetrical hollow (Figure 6); it is significantly less strong than a cylinder with a symmetrical hollow.

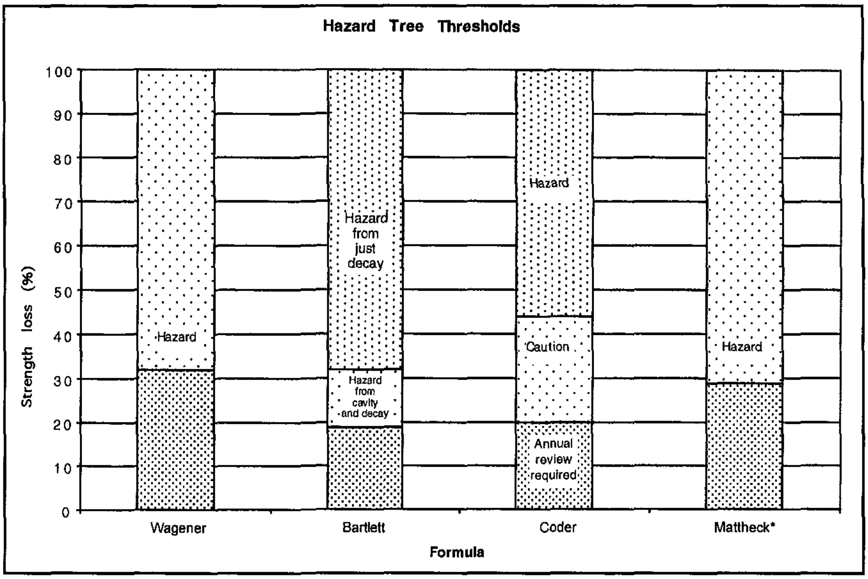

Figure 2. Hazard tree strength loss thresholds, according to various formulae. Mattheck's formula has been converted to a percentage and inverted to compare with the other formulae. Each formula describes when a tree becomes a hazard, but many complicating factors exist and each author strongly cautions against drawing a rigid line between hazardous and nonhazardous trees (Wagener 1963; Coder 1989; Smiley and Fraedrich 1993; Mattheck and Breloer 1998).

a cylinder is based on the diameter of the cylinder raised to the fourth power (D^4). The moment of inertia (I) of a body describes the body's resistance to bending stress and is directly proportional to its size; larger-diameter cylinders take more force to bend and distribute the force of the bending moment across more area. In calculating the bending stress (stress is force per unit area) on a body, engineers use the formula, $\sigma = (-M * y) \div I$, where σ is bending stress, M is the bending moment, and y is the distance to the perimeter of the body). The formula shows how the moment of inertia (I) is inversely proportional to bending stress. To find the strength loss between hollow and solid cylinders of homogeneous, isotropic material, such as a steel rod and a steel pipe, one applies the formula $d^4 \div D^4$; d and D are as above.

Since trees are not perfect cylinders, wood is an orthotropic and heterogeneous material, and trees exhibit peculiarities such as branch attachments, reaction wood, and asymmetrical decay pockets, using $d^4 \div D^4$ is not as appropriate with trees (Wagener 1963; Coder 1989; Matheny and Clark 1994). Wagener therefore modified the formula to make more conservative estimates of strength loss, raising the diameters of hollow and sound wood only to the third, not the fourth, power ($d^3 \div D^3$) (Wagener 1963). Wagener acknowledged that his formula was applicable only to softwoods with decay in their stems. This is so because excurrent trees (such as the West Coast conifers Wagener studied) are most likely to fail at the stem (Wagener 1963; Wallis et al. 1980). When decay is the defect, excurrent trees, with single straight stems supporting small lateral branches, generally fail by stem breakage. This is so because stem decay can extend only into the small lateral branches (forest-grown excurrent trees do not have large subordinate branches). Decurrent trees infected with decay, on the other hand, usually fail at branch attachments where the stem decay extends into large subordinate branches (Wagener 1963; Matheny and Clark 1994). Conversely, trunk decay combined with large, healthy subordinate branches can make the tree susceptible to sudden branch pullout and failure, especially during periods of hot, dry weather (Shigo n.d.). Citing experience and observation, Wagener decided that a conifer could withstand a 33% loss in strength without becoming a hazard. The 33% strength loss corresponded to a 70% loss of heartwood according to Wagener's formula (Figure 3). He cautioned, though, that these figures were applicable only to conifers in the absence of other defects such as cracks, cankers, or a lean (Wagener 1963).

Adopting the moment of inertia formula from mechanics of solids, based on the hollow and solid stem diameters raised to the fourth power ($d^4 \div D^4$), Coder created a hazard threshold graph (Figure 4). When strength loss from the formula meets or exceeds 45%, a hazard exists; when strength loss is

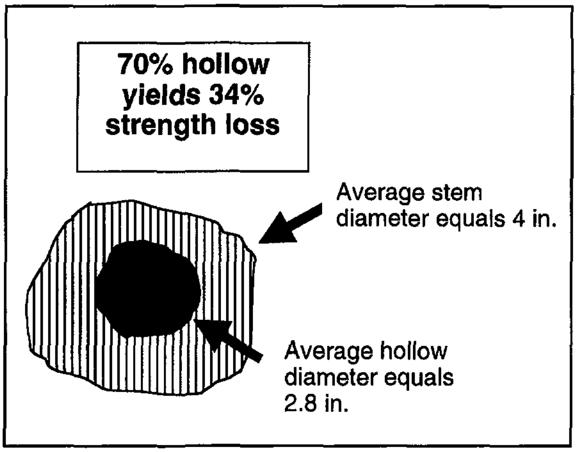

Figure 3. According to Wagener's formula, a 4-in. diameter tree stem loses 34% of its strength when decay or a hollow occupies 2.8 in. of the center of the stem (Wagener 1963).

between 20% and 44%, the tree is in the caution zone and must be evaluated with respect to other defects (such as cracks, lean, or cavities) that could contribute to the hazard. Agreeing with Wagener, Coder cautions that the $d^4 \div D^4$ formula is applicable only to perfect cylinders under ideal test conditions. Certainly, trees in nature subjected to wind and other loads do not fit those requirements (Coder 1989).

To account for open cavities in stems, researchers at the Bartlett Tree Research Lab modified Wagener's formula to include a term for strength loss due to an open cavity. This is an important inclusion because open cavities remove the outer tree rings, the tree rings that provide the most strength. Referring to mechanics of solids, the generic formula for (I), used when an area does not conform to a geometric shape, is $I = \Sigma AD^2$, where A is an element of area and D is the distance from each element of area to the centroid of the whole area. The D^2 term indicates that distance from the centroid contributes exponentially to strength of the area. Bartlett's formula is strength loss = $(d^3 + R(D^3 - d^3)) / D^3 * 100$, where D and d are as above, and R is the ratio of cavity opening to stem circumference (Figure 5). Bartlett accepts the 33% strength loss as an acceptable hazard tree threshold but uses 20% when other defects or severe stresses are present. During a study conducted after hurricane Hugo, Smiley and Fraedrich (1992) evaluated the efficacy of their formula and hazard thresholds. Using the 33% and 20% strength loss thresholds, their formula would have accurately predicted half of the tree failures due to hurricane force winds (up to 90 mph for Hugo) while removing only 12% of trees with decay that did not fail (Smiley and Fraedrich 1992, 1993). Currently, however, Bartlett advises against using a strength loss formula and instead has developed a table of sound wood thresholds for given amounts of decay or cavity opening (Fraedrich 1999).

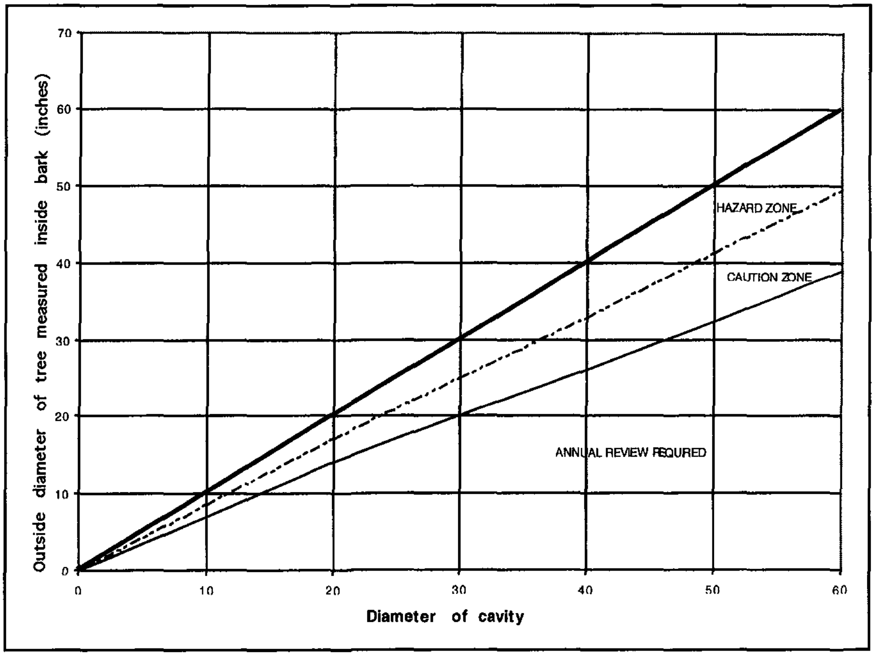

Figure 4. Strength loss graph to accompany Coder's $d^4 \div D^4$ formula. Trees having lost 20% to 44% of their strength due to decay are in the caution zone; when strength loss rises above 44%, the tree should be considered hazardous (Coder 1989).

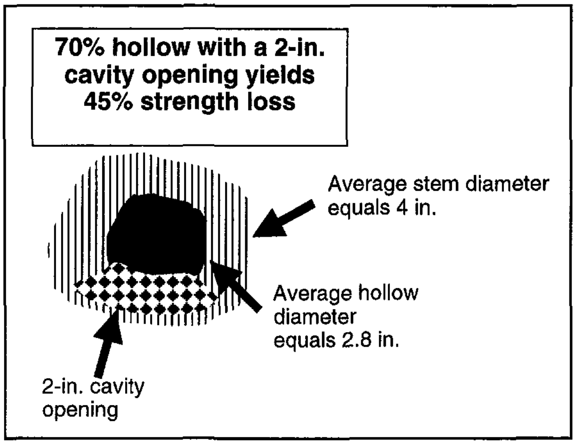

Figure 5. According to the Bartlett formula, a 4-in. diameter tree stem that is 70% hollow and has a 2-in. wide cavity opening loses 45% of its strength (Smiley and Fraedrich 1993).

Mattheck developed a hazard tree threshold formula based on the buckling strength of a cylinder. When the ratio $t \div R \geq 0.3$, where t equals the thickness of sound wood remaining in a stem and R equals the radius of the stem, the tree is unlikely to fail due to the amount of decay in the stem (Mattheck and Breloer 1998). After looking at more than 800 broken and standing trees, Mattheck showed that no trees with $t \div R \geq 0.3$ failed; conversely, when $t \div R < 0.3$, most of the trees failed. Some trees still standing despite $t \div R < 0.3$ were standing dying snags, with only single or a few remaining branches; this clearly decreases the load on the tree stem, allowing it to remain standing despite a thin layer of sound wood (Mattheck and Breloer 1998). The results are interesting because the formula applies without caveat; that is, it is appropriate for all sizes and species of trees. The $t \div R$ formula applies to failure from what Mattheck and Breloer describe as cross-sectional flattening and shell-buckling, since it assesses the remaining wall of sound wood thickness. Engineers describe this type of failure as Brazier buckling or thin-walled buckling. Failure from bending stress (i.e., when the remaining sound wall is relatively thick compared to the stem diameter) is likely only when a cavity also occurs on the stem (Mattheck and Breloer 1998). As noted below, there are several types of tree failure described from a mechanical point of view, some are more likely to occur than others (Mattheck and Breloer 1998). The $t \div R$ formula does not account for other stem defects but can account for off-center decay columns. In stems where decay is not aligned with the stem center, the $t \div R$ values are taken from the thinnest remaining wall and the radius of the decay column plus the remaining wall thickness (Figure 6). The presence of other defects would weaken the stem further, but the $t \div R$ value appears to be a good starting point to predict failure from cross-sectional flattening and shell-buckling (Mattheck and Breloer 1998).

Mattheck and Breloer (1998) describe several different types of failure a tree stem can undergo. Simple bending fracture, where stem fibers buckle in compression under load, occurs only in solid stems and usually where a stem imperfection, such as a branch stub or open cavity, exists. Wood is stronger in tension than in compression (Hoadley 1980; Forest Products Laboratory 1999), so failure occurs on the leeward side as the fibers are compressed (Mergen 1954; Wagener 1963; Mattheck and Breloer 1998). As the load bends the stem, fibers in compressive stress buckle and eventually allow the stem to bend enough to cause the fibers on the opposite side of the stem (under tensile stress) to split apart axially. Living trees can sustain compression failure on their leeward side during strong winds, as long as the tensile strength of the fibers on the windward side is not exceeded. Once compression failure has occurred, the stem is susceptible to further compression failure at the point of weakness caused by the original compression failure. Eventually, enough fibers will have buckled under compressive stress to the point that the remaining tensile strength of the tree cannot support wind loads and the stem fails (Mergen 1954). The disparity between tensile and compressive strengths of wood is mitigated to a certain degree by the inherent tensile stress formed by growth stresses in the outer portions of a tree stem (Mattheck and Kubler 1995).

However, simple bending fracture is not common in the absence of other defects, and trees with large hollows from decay (leaving relatively thin remaining walls) fail by a different means (Mattheck and Breloer 1998). When trees have a hollow center (or a center filled with decayed wood), the remaining stem wall thickness determines failure mode. Under a bending load, stems with relatively thin remaining walls fail by cross-sectional flattening, Mattheck and

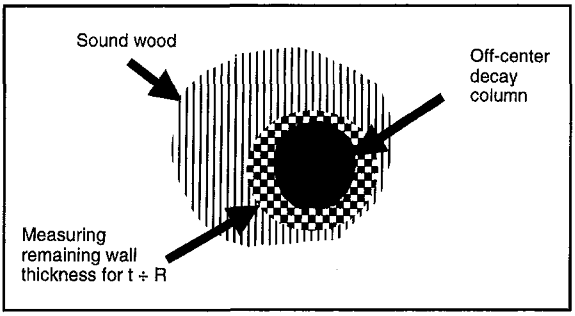

Figure 6. Cross-sectional view inside a cut tree stem of an asymmetrical decay column. The column of decay is offset from the center of the stem, which increases strength loss in the stem. For Mattheck's $t \div R$ formula, the remaining wall thickness is measured based on the thinnest remaining wall (Mattheck and Breloer 1998).

Breloer use the analogy of bending a garden hose and watching how the walls "flatten" as the hose bends. Stems whose remaining walls are thinner still fail by shell-buckling, whereas axial splits cause a splintering effect under bending load. Their analogy here is of an aluminum can collapsing under bending (Mattheck and Breloer 1998). In both cases, longitudinal fracture—not the fiber buckling associated with simple bending fracture—causes stem failure. In cross-sectional flattening, the process can be slowed by the presence of decayed wood in the stem (as opposed to a completely hollow stem). Shell-buckling is notorious for its unexpected behavior (Mattheck and Breloer 1998). Interestingly, bending strength losses up to 70% can accompany even early stages (as classified by a 5% to 10% wood weight loss) of wood decay (Wilcox 1978). Some sources note that if decay is detectable, the wood should be considered to have very little residual strength properties (Wilcox 1978; Forest Products Laboratory 1999; Matheny and Clark 1999). Mattheck and Breloer (1998), however, suggest that even the decayed wood in the center of a hollow tree can reduce cross sectional flattening probability.

Except for Mattheck's $t \div R \geq 0.3$, the strength loss from decay formulae discussed above do not account for a decay column that is not aligned along the center of the stem. Off-center decay columns can significantly reduce the bending strength of the stem. This can be illustrated by looking at the moment of inertia (I) of a cylinder. Given a 4-in. diameter cylinder, $I = 12.57$ in^4; if the 4-in. stem has a 2-in. diameter hollow center, $I = 11.78$ in^4, a 7% decrease; if the 2-in. hollow is offset to the periphery of the cylinder, $I = 8.64$ in^4, a 27% reduction. In Figure 1, the curve "I offset hollow" represents the strength loss of a cylinder with an offset hollow, calculated using the mechanics of solids formula. The curve reflects the greater strength loss due to an asymmetrical hollow in a tree stem and highlights a shortcoming of some of the strength loss formulae.

In many cases, decay is formed asymmetrically and makes the strength loss formulae less appropriate to use. Wounds that injure the periphery of a stem or branch (for example, when an automobile hits a tree and removes the bark) create decayed areas immediately around the wound. The decay therefore affects the outer wood and creates an asymmetrical decay area, not centered along the pith. As the tree grows and compartmentalizes the wound, the decayed area remains off center until the tree grows large enough that the decay eventually becomes centered. However, in older trees, the decay may never become centered, remaining instead near the periphery of the stem, even if new wood has closed over the old wound (Shigo and Larson 1969; Shigo 1977, 1979).

Wagener's, Coder's, Mattheck's, and Bartlett's formulae differ in the strength loss estimates they provide given a specified amount of decay in a tree stem. Additionally, the Bartlett formula differs in that it accounts for open cavities, which the other formula do not. Finally, Mattheck's formula is based on buckling theory, not bending theory, and his formula estimates the failure potential based on a different type of tree failure. Whereas Mattheck's formula addresses the likelihood of stem failure due to cross-sectional flattening and buckling, Wagener's and Coder's formulae calculate bending strength loss in the stem, from mechanics of solids. In addition to the strength loss calculation, each author offers thresholds to determine when strength loss exceeds safety margins. Figure 2 shows the hazard thresholds as a function of the strength loss of the tree stem. Each author emphasizes the imprecision of hazard tree assessment and cautions against using the thresholds as strict guidelines for determining whether a tree is a hazard. This is in consensus with the literature, as hazard tree managers and researchers are aware of the complexity of the issue (Wagener 1963; Coder 1989, Smiley and Fraedrich 1993; Matheny and Clark 1994, 1999; Mattheck and Breloer 1998).

TREE STEM AND WOOD VARIABLES

Applying strength loss formulae from mechanics of solids to trees is complicated and imprecise. Mechanics of solids formulae are derived for perfect geometric shapes and bodies made of homogeneous material. Although a tree resembles a cylinder, it is not geometrically perfect. Similarly, wood is not a homogenous material, exhibiting a suite of variables that affect strength properties. Forest products researchers have tested wood strengths extensively for many years, comparing different species and different strength properties (Forest Products Laboratory 1999). This section describes the various wood characteristics that influence strength properties. Many standard tests are conducted to determine wood strength (American Society for Testing and Materials 1971). The test used most commonly to determine wood strength of beams in use is the static bending test (ASTM D-143 standard), which gives a value for modulus of rupture (MOR). Modulus of rupture reflects the maximum load-carrying capacity of a member in bending (Forest Products Laboratory 1999) and is a good test to measure bending strength of wood.

Wood is an orthotropic material; its strength properties differ as a function of the direction in which a force acts. Wood is stronger in tension than in compression; fibers will buckle before they tear. This is not true of steel, which is equally strong in tension and compression. Tensile strength can be two times as great as compressive strength in wood (Kollman and Cote 1968; Hoadley 1980; Mattheck and Breloer 1998; Forest Products Laboratory 1999). Trees can sometimes exhibit local compressive failure but remain standing since tension wood can compensate for the compressive strength loss (Mergen 1954; Mattheck and Breloer 1998). Loaded beyond its breaking strength, sound wood will fail first in compression, then in tension (Wagener 1963; Hoadley 1980; Mattheck and Breloer 1998).

Tree stems are not made of a homogeneous material, unlike a manufactured product such as steel. Wood is composed of various types of cells: vessels, tracheids, and fibers that vary in their chemical and physical compositions. Environmental factors (climate and geology), tree genetics, and tree age all affect the proportions of the different cells in a tree stem. Consequently, different tree species vary in wood strength; trees of the same species also vary in wood strength. Even an individual tree has wood of varying strength in different parts of the stem and canopy (Kollman and Cote 1968; Panshin and DeZeeuw 1980; Forest Products Laboratory 1999). Generally, heavier wood is stronger than lighter wood, since there is more wood substance relative to air in a given volume. Specific gravity is the most reliable single indicator of wood strength (Hoadley 1980; Panshin and DeZeeuw 1980; Forest Products Laboratory 1999), and it reflects relative wood density; that is, the amount of cell wall substance for a unit of volume. Specific gravity is affected by growing conditions such as available water and nutrients, temperature, and canopy position (overstory or understory) (Panshin and DeZeeuw 1980).

In temperate climates, early in the growing season, water is plentiful and trees grow more quickly. In addition, apical growth and leaf production compete with cell wall production for available carbohydrates. As a result, cells cavities are generally larger and cell walls generally thinner, to facilitate conduction. Wood produced early in the season is called earlywood; wood produced later in the season is called latewood. Since earlywood has larger cells and is therefore less dense than latewood, it also affects strength properties (Hoadley 1980; Panshin and DeZeeuw 1980). Latewood is often three to four times as dense as earlywood; strength and stiffness properties reflect similar or greater distinction. The tensile strength of mature latewood of shortleaf pines was found to be five times as strong as the tensile strength of earlywood from the same trees (Bodig and Jayne 1982). Kollman and Cote cite similar findings for pines in Finland (1968).

Growth rate affects strength differently in different species. In conifers, the proportion of latewood in a year is relatively unvaried. Instead, growth rate changes influence the proportion of earlywood. This means that slow growth will increase the proportion of latewood to earlywood, making the wood denser, and therefore stronger (Hoadley 1980). In ring-porous hardwoods, on the other hand, the earlywood proportion is relatively consistent, while growth rate influences the proportion of latewood. In this case, faster growth creates denser wood, since there is more latewood (Hoadley 1980). Since climate affects wood density and therefore strength properties, geographic location naturally will affect strength properties as well. Wood of several southern pine species varies in specific gravity from northwest to southeast in the species' natural ranges (Panshin and DeZeeuw 1980). To illustrate the variation inherent in wood of a given species, the results of repeated static bending tests for 50 different tree species have shown an average coefficient of variation of 16% for MOR. The average coefficient of variation is taken from tests on clear, straight-grained (i.e., defect-free) test pieces and does not reflect the variability due to other defects and inherent wood variables (Forest Products Laboratory 1999).

Other wood variables include spiral grain, reaction wood, juvenile wood, large earlywood rings (Hoadley 1980), and branch attachments. Each of the aforementioned variables influences wood strength properties, creating a complex suite of variables in a living tree. Because of the complexity of tree anatomy, it is impossible at this time to apply a strength loss formula that is appropriate for any tree stem.

Reaction wood forms when trees are bent out of shape; for example, a leaning tree produces reaction wood to prevent further lean and attempt to correct direction. Reaction wood in conifers is called compression wood and it grows on the underside of a leaning stem. In deciduous trees, reaction wood is called tension wood and it grows on the upper side of the stem. Reaction wood is denser than normal wood but displays abnormal strength behavior (Panshin and DeZeeuw 1980; Forest Products Laboratory 1999). In some species, reaction wood has a greater MOR; in others, the MOR is less (Panshin and DeZeeuw 1980). Reaction wood tested in green condition (normal moisture content) is stronger in compression and toughness tests than normal wood. This has been attributed to the increase in lignin content in the cell walls (Panshin and DeZeeuw 1980). Physical and mechanical properties of tension wood generally deviate less from normal wood than compression wood, in which marked differences in physical and mechanical properties occur (Panshin and DeZeeuw 1980; Forest Products Laboratory 1999).

Juvenile wood is the wood formed immediately outside the pith and it can encompass from five to twenty rings, depending on the tree species. Because juvenile wood cells differ in composition and size, juvenile wood has unpredictable strength properties (Panshin and DeZeeuw 1980; Forest Products Laboratory 1999) and frequently results in brash failure in bending tests. Brash failure is noted as an abrupt failure with minimal deflection of the member (Hoadley 1980). Juvenile wood tends to be more exaggerated in conifers than in deciduous trees (Panshin and DeZeeuw 1980).

CONCLUSION

The question of when a tree becomes a hazard is important because when trees fail, they can injure persons and damage property. As liability continues to be a concern when injury or damage occurs, it behooves the arboriculture community to agree upon guidelines for determining when a tree is hazardous. With an industrywide standard, arborists involved in hazard tree management will be better prepared to defend and rationalize decisions to remove or not remove potentially hazardous trees. As this paper has shown, there are differences between the various hazard tree strength loss formulae and the threshold(s) each offers for considering a tree hazardous. Since trees are complex, living organisms, it is difficult to quantify and precisely measure all variables when inspecting a standing tree for hazard. Research is needed to show that a particular formula does accurately reflect strength loss. Research is also needed to address the question of critical loads a tree can sustain before failure.

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Résumé. Les arbres dangereux constituent des pré-occupations pour tous ceux qui ont à gérer les arbres en milieu aménagé, ce autant les arboriculteurs que les forestiers urbains et les gestionnaires de territoire. Au travers des recherches, de l'expérience, des observations et du bon sens, les arboriculteurs et les forestiers urbains ont identifiés plusieurs facteurs de risques qui prédisposent les arbres à se casser. Ils ont aussi développé des seuils de tolérance afin de s'aider à déterminer le degré de risque, à savoir si un arbre est en danger imminent de se briser ou s'il nécessite des inspections annuelles ou mêmes plus fréquentes. Deux facteurs critiques sont impliqués dans l'évaluation de la perte de résistance des tiges d'un arbre comportant des défauts. En premier, il est important de connaître le degré de résistance structurale perdu imputable au défaut structural tel une blessure ouverte ou une cavité interne. En second lieu, la charge ou la force requise pour provoquer le bris doit aussi être pris en considération étant donné que le bois de certaines espèces est naturellement plus résistant que celui d'autres. Les recherches en cours à l'Université du Massachusetts ont pour but de tester la perte de résistance structurale dans les tiges qui est imputable à la carie. Éventuellement, lorsque la méthodologie sera raffinée, d'autres défauts structuraux seront aussi évalués. Un besoin pour ce type de recherche existe parce que les arbres dangereux posent une question de responsabilité importante et aussi parce que peu d'essais quantitatifs ont été faits pour établir les seuils de tolérance permettant de classifier les arbres comme dangereux.

Zusammenfassung. Standsicherheitsgefährdete Bäume sind ein Problem für jeden, der Bäume in einer Landschaft zu verwalten hat, einschließlich Arboristen, Forstleute und Grundstücksverwalter. Durch Forschung, Erfahrung, Beobachtung und gesunden Menschenverstand haben Arboristen und Forstleute viele Risikofaktoren identifiziert, die eine Prädisposition zum Versagen darstellen. Sie haben auch Schwellenwerte entwickelt, um den Schadensgrad zu bestimmen, ob ein Baum nun in unmittelbarer Gefahr ist, zu stürzen, oder aber jährliche Inspektionen benötigt. Zwei kritische Faktoren beziehen eine Überprüfung des Stärkeverlustes von Stämmen mit Defekten ein. Erstens ist es wichtig zu wissen, wie viel Stabilität durch so einen Defekt oder Kavität verloren geht. Zweitens muß die Last einbezogen werden, die für ein Umstürzen erforderlich ist, da das Holz einiger Baumarten wesentlich stärker ist als bei anderen. Die gegenwärtige Forschung an der Uni von Massachusetts beabsichtigt, den Stabilitätsverlust durch Fäulnis in Stämmen zu testen. Wenn die Methode sich bewährt, werden eventuell auch andere strukturelle Defekte getestet werden. Es besteht ein Bedarf an solcher Forschung, weil gefährdete Bäume ein großes Haftungsrisiko bergen und weil bislang relativ wenig quantitative Testreihen ausgeführt wurden, um Grenzwerte für eine Klassifizierung zu etablieren.

Resumen. Los árboles de riesgo son una preocupación para cualquiera que maneje árboles en un paisaje, incluyendo arboristas, dasónomos urbanos y administradores de terrenos. A través de la investigación, experiencia, observación y sentido común, los arboristas y los dasónomos urbanos han identificado muchos factores de riesgo que predisponen los árboles a la falla. También han desarrollado procedimientos para ayudar a determinar el grado de riesgo, sea que un árbol se encuentre en peligro inminente de caer o que necesite inspecciones anuales (o más frecuentes). Dos factores críticos están envueltos en la pérdida de resistencia de los troncos de los árboles con defectos. Primero, es importante conocer cómo se pierde esta resistencia debido a defectos tales como cavidades. Segundo, la carga requerida para causar la falla necesita ser considerada, siendo que la madera de algunos árboles es más resistente que la de otros. La investigación llevada a cabo en la Universidad de Massachussets intenta probar la pérdida de resistencia debida al decaimiento en los troncos de los árboles. Eventualmente, una vez refinada la metodología, se podrán probar otros defectos estructurales. Es necesaria esta investigación debido a la importancia de los árboles de riesgo y por las pocas pruebas hechas para establecer procedimientos para clasificar los árboles peligrosos.