DETERMINING STRENGTH LOSS FROM DECAY

by E. Thomas Smiley and Bruce R. Fraedrich

Abstract. A formula for assessing strength loss due to decay was tested on hurricane broken trees and surviving trees exposed to hurricane force winds. When the formula was used with a 33% strength loss threshold, it would predict 50% of the failures in 90 mph winds while calling for "unnecessary" removal of 12% of surviving decayed trees.

Large trees in the urban forest are declining at an alarming rate (3). At the same time, society is becoming more litigious. This combination of events demands that the detection, evaluation and management of hazardous trees must be the first priority for arborists and urban foresters.

A tree is hazardous if it has both a structural defect that predisposes the tree to failure, and a target that would be struck if it were to fail. Healthy trees may be hazardous if they obstruct motorist's vision, raise sidewalks, interfere with utilities, or are particularly attractant to lightning.

Many kinds of structural defects must be considered when evaluating a tree. Some of these defects are illustrated in Figure 1 and more have been described in the literature previously (2, 4, 6).

Evaluation of strength loss from decay in the trunk, limbs or roots has always been a problem for the arborist. It is well known that decay will structurally weaken the tree, but how much is too much? In the past the answer to this question was often based on qualitative factors as the experience of the arborist, budget constraints, and the attitude of the property owner.

In 1963 the United States Forest Service published a paper by Wagener (6) that documented tree failure in campgrounds. This was the first attempt to quantify a factor associated with tree failure. Using measurements of the diameter of the hollow crosssection of the trunk (d) and diameter of sound wood (D) the amount of strength loss (SL) was determined.

The formula $SL\% = d^4/D^4 \times 100$ was originally developed by engineers, to compare the strength of pipes. Wagener modified it to take into account the irregularities of trees ($SL\% = d^3/D^3 \times 100$). Coder (1) has used the original engineering formula ($SL\% = d^4/D^4 \times 100$) to estimate strength loss. He established zones in the tree where strength loss from decay was excessive, marginal and acceptable.

This study was undertaken to evaluate the structural strength loss in trees with trunk decay which failed or withstood hurricane force winds in Charlotte, NC. The data were then used to evaluate threshold values for decay.

Materials and Methods

Oak trees (mostly *Quercus alba, Q. falcata* and *Q. phellos*) in the Charlotte, North Carolina area which were broken, not windthrown, following 90 mph winds of hurricane Hugo were selected for measurement. Trees were selected from planted urban areas including street, park and yard trees; from an arboretum; and from a forested county park. One hundred non-damaged "control" trees were selected from the same areas. Selection was made so that the species distribution and mean diameter of each group would be nearly equal. Only standing trees that were found to have more than 10% strength loss from trunk decay were selected for the control group.

Bark thickness, trunk diameter at the weakest point (i.e., at the point of breakage or height of largest opening), thickness of sound wood from at least three locations at the selected height, and width of an opening were measured. Strength loss was determined using the formula:

$$SL\% = \frac{d^3 + R(D^3 - d^3) \times 100}{D^3}$$

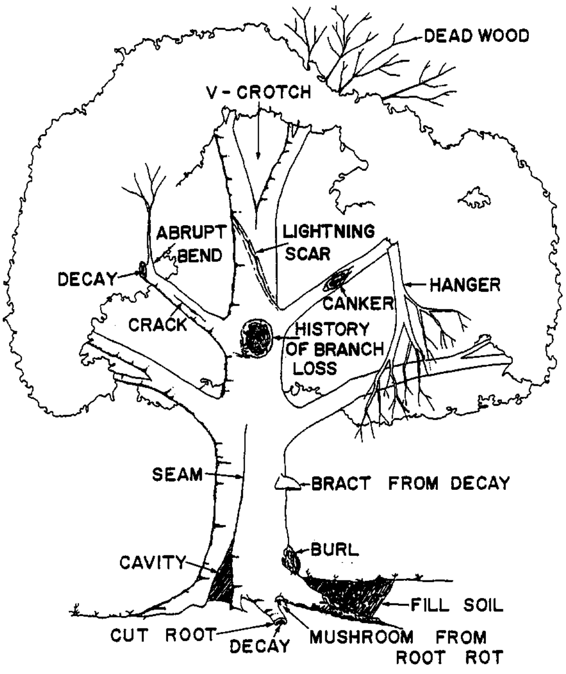

Figure 1. Some of the defects which may be associated with hazardous trees.

Where SL = Strength loss
d = Diameter of hollow and/or nonstructurally sound wood
D = Diameter of sound wood
R = Ratio of cavity opening to stem circumference

The $R(D^3-d^3)$ modification to Wagener's formula was developed by the Bartlett Tree Research Laboratories to account for wood which is "missing" at a cavity opening (2, 5). Measurements of sound wood thickness were made by drilling with an 1/8" diameter bit until resistance decreased when decayed tissues were encountered. The inserted portion of the bit was then extracted and measured to determine this thickness of sound wood. On broken trees, the thickness of sound wood was measured on the exposed surface.

Results

Fifty four trees broken by the hurricane were examined. Over 100 standing trees which had symptoms of decay were tested, 31 trees having more than 10% strength loss from decay were included in the standing population (Figure 2). The average diameter of broken trees was 22.3 inches (57.1 cm) with a standard deviation of 12 inches (30.5 cm). The standing decayed trees had an average diameter of 22.7 inches (57.7 cm) with a standard deviation of 10.2 inches (25.9 cm).

Of the 54 broken oaks, 52 had internal decay. Strength loss varied from less than one percent to greater than 90%. The average strength loss was 33% with a standard deviation of 22%. Control trees had an average strength loss of 23% with a standard deviation of 11%. Four of the 31 standing trees had a strength loss greater than 33%.

Discussion

The Bartlett modified strength loss formula was relatively easy to apply to both standing and broken trees. There was an obvious difference in the amount of decay between standing and broken trees. The question then occurs, "how much decay is too much?"

Many factors influence the structural stability of a tree and its capacity to survive windstorms. The presence and severity of decay in the stem is a major factor which predisposes trees to failure. Tree species, crown size, crown density, branching structure, leans, location of decay in trunks and limbs, site factors such as exposure, and storm severity also influence tree failure.

The selection of a threshold for removal of decayed trees is not an easy task. If set too high, failures could occur which result in unnecessary injury. If set too low, many trees will be unnecessarily removed. Ideally, the threshold would have predicted all of the trees that failed and would not have called for any unnecessary removals.

Comparing various formula threshold values with the percentage of trees saved or removed when the threshold is applied shows that none of the values comes close to the ideal (Table 1). The lower the threshold value the lower the percentage of broken trees which would have been recommended for removal. As the threshold increases so do both the necessary and unnecessary removals.

There are two factors that can be used to assist in threshold selection. First, it should be selected to

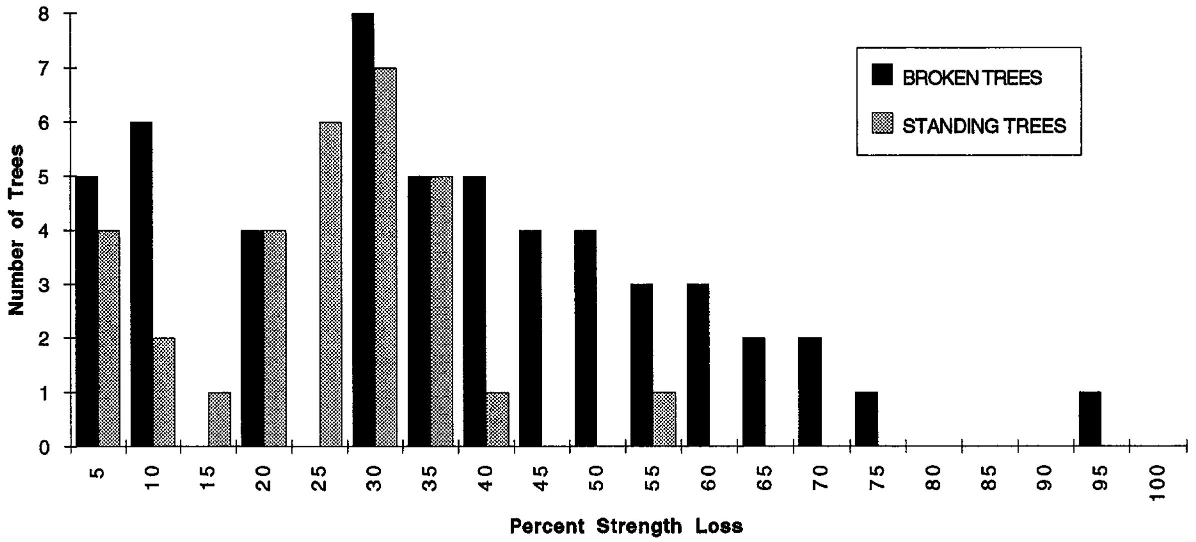

Figure 2. Number of trees in each 5% strength loss class which were broken or were decayed and remained standing after 90 mile per hour winds.

maximize the removal of trees that would fail in normally encountered wind storms. It is not expected that all trees be able to withstand 90 mph winds without failure.

Second, the threshold should maximize the difference between the number of trees that are necessarily removed and those that are unnecessarily removed. With any threshold value, some trees that would survive a wind storm will be removed. These trees may be protected by other trees, buildings or they may be exceptionally strong. If the wind were from a different direction or if the crown developed a higher density, this storm resistance may not occur.

The use of 33% strength loss as a threshold for removal has been suggested for west coast conifers (6). Coder (1) using the d^4/D^4 formula defined a hazard zone with 20 - 44% SL. The data

Table 1. A comparison of threshold values by using data generated from decayed trees broken and standing after 90 mph winds.

% Strength loss threshold*	% Broken trees which would have been		% Standing trees which would have been		
	Saved	Removed	Saved	Removed	Difference(%)
10	21	79	16	84	-5
20	29	71	32	68	3
30	44	66	71	29	37
33	50	50	87	13	37
40	63	37	97	3	34
50	79	21	97	3	18
Ideal	0	100	100	0	100

*Trees with strength loss greater than or equal to the threshold would have been recommended for removal, other trees would have been saved.

in Table 1 show that a threshold between 30 and 40% SL would remove a high percentage of broken trees while minimizing the number of unnecessary removals.

A 33% threshold would have removed half the trees that failed from 90 mph winds but would have removed only 12% of the decayed trees that withstood hurricane Hugo. Most arborists would have selected a lower threshold for many more of the trees which failed. Lower thresholds are needed for trees with weak wood, decay in crotches, high crown densities, leans or those in more exposed areas. For these trees a 20-25% threshold may be appropriate.

After several years of widespread use of the formula method for decay assessment by Bartlett arborists, we are convinced of its value. Professional judgement still plays an important role. However, an objective estimate of strength loss provides an important first step in tree assessment.

Summary

Analysis of structural weakness caused by decay has always been difficult. Scientifically based quantification of strength loss is an important first step in reducing the guess work associated with hazard assessment. Many more of the failed trees would have been removed if the threshold were adjusted due to additional defects such as weak wooded species, decay in crotches, high crown densities, leans or those in more exposed areas.

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Bartlett Tree Research Laboratories
13678 Hamilton Road
Charlotte, NC 28278

Resumé. Une formule pour évaluer la perte en robustesse due à la carie était testée sur des arbres cassés par un ouragan et sur des arbres survivants exposés aux vents violents de l'ouragan. Lorsque la formule était employée avec un seuil de perte en robustesse de 33%, elle prédisait 50% d'échec avec des vents de 90 MPH (145km/h) alors qu'elle faisait état d'une non-nécessité à enlever 12% des arbres cariés survivants.

Zusammenfassung. Eine Formel zur Abschätzung der verringerten Festigkeit durch Holzfäule wurde an Bäumen überprüft, die durch einen Hurrikan umgebrochen wurden und an welchen, die diesen überlebten. Wenn die Formel benutzt wird mit einem Schwellenwert von 33% Festigkeitsverlust werden bei einer Windgeschwindigkeit von 160 km/h 50% der Versager vorhergesagt, während nur 12% der Bäume mit Fäulnis aber mit noch ausreichender Bruchfestigkeit unnötigerweise entfernt werden.