

Branch Strength Loss Implications for Silver Maple (*Acer saccharinum*) Converted from Round-Over to V-Trim

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Abstract. Trees converted from round-over to V-trims could develop a canopy of potentially weak watersprouts growing on parent stems with a high probability of decay. This study was conducted to determine if the conversion from round-over to V-trimming predisposes silver maple (*Acer saccharinum* L.) trees to failure, and if decay is more likely to occur in watersprouts arising after heading cuts than in branches arising from lateral buds. Watersprouts were mechanically pulled from converted trees and found to be 49% weaker than normally occurring branches. Branch strength at failure (stress) decreased as watersprouts grew in size, and decay was present in over one-half of the watersprout at the point of failure. The conversion from round-over to V-trimming appears to predispose silver maple trees to failure.

Key Words. Decay; line clearance; round-over; silver maple; strength loss; stress; topping; utility arboriculture; V-trimming; watersprout.

Trees in utility rights-of-way require repeated cycles of trimming to maintain safe, reliable electric power. Tree crews are limited in the types of trimming that can be used to maintain conductor clearance for trees growing directly under the power lines. Traditionally, many utilities used round-over trimming to remove the canopy to a predetermined point leaving a symmetric crown below the conductors. Over the past few decades, directional pruning techniques have been adopted by many utilities, and V-trimming is used in trees below the conductors. V-trimming removes the interfering branches in the center of the tree and leaves the exterior portion (Johnstone 1983; Gilman 2002).

Branches normally arise from lateral buds that are formed in the axil of the leaves along the parent stem (Kozlowski and Pallardy 1997). A newly forming lateral branch often forms a collar of overlapping branch and parent limb tissues (Shigo 1985; Neely 1991). Round-over trims are initiated by making heading cuts, which removes a branch at a point not associated with a lateral branch or bud (American National Standards Institute 2001; Gilman 2002; Harris et al. 2004). In response to the heading cut, many trees produce numerous shoots from dormant, or latent, buds with a bud trace to the parent stem's pith (Maillette 1982; Kozlowski and Pallardy 1997) or from adventitious buds that are not connected to the parent stem's pith (Kozlowski and Pallardy 1997). These vigorously growing shoots are often called watersprouts (Gilman 2002; Harris et al. 2004). As the watersprout grows, initially there is little, if any, formation of a branch collar (Shigo 1989) and they are considered weak.

Watersprouts arising after a heading cut are likely growing on parent stems (leaders) that, anecdotally, have a high prob-

ability of decay. If decay continues to spread, the parent stem may not be able to support the watersprouts as they increase in size. Indeed, internal decay columns were present in 90% of leaders in silver maple trees converted from round-over to V-trims (Dahle et al. 2006). Additionally, decay may breach barrier zones in the leader and move into the rapidly growing watersprout, thus escalating the potentially weak nature of the watersprout.

Tree structure research has concentrated on normally developed branches, particularly those arising from lateral buds. Lilly and Sydnor (1995) found branch strength to be the same in silver maples (*Acer saccharinum* L.) and Norway maple (*A. platanoides* L.). Furthermore, MacDaniels (1923 and 1932) and Miller (1958) with apple trees (*Malus* spp.) and Gilman (2003) with red maples (*A. rubrum* L.) showed that as the aspect ratio (branch diameter/trunk diameter) increased, the force needed to create a failure in a branch decreased. An investigation of codominant stems (high aspect ratio) in red maples determined that the presence of included bark reduced the strength of branches by 14% to 20% (Smiley 2003). Although previous studies have investigated the strength of normally occurring branches, this study was designed to (1) determine if watersprouts arising after heading cuts are as strong as normally developing lateral branches, and (2) determine if decay is more likely to occur in watersprouts arising after heading cuts than in normally developed branches.

Silver maple was chosen as the test species because it is a frequently occurring urban tree in the U.S. Midwest, is subjected to heading cuts during utility-line clearance activities, and is often topped along roadsides or in private yards (Karlovich et al. 2000; Gartner et al. 2002). In addition, silver

maple has one of the lowest modulus of rupture (MOR) or breaking strength of hardwood species tested by the Forest Product Laboratory (U.S. Forest Products Laboratory 1999).

METHODS

Sampling occurred on silver maple trees located in Tippecanoe County in central Indiana, U.S. Treatment trees were trees subjected to round-over trimming followed by an ongoing conversion to V-trims during line clearance operations (Figure 1). Control trees were located in Tippecanoe County at the Purdue Wildlife Area, owned and managed by the Purdue University Department of Forestry and Natural Resources. Based on observed structure, the control trees did not appear to have a history of pruning or storm damage.

Watersprouts arising after heading cuts made on the leaders were mechanically tested on the treatment trees (Figure 2), and naturally arising branches were tested on the control trees. Although multiple watersprouts occurred on most leaders, only one watersprout per leader was tested for failure strength (stress). Watersprouts arose below the most recent heading cut made along the leaders. Although some of the watersprouts showed signs of lateral cuts made during line clearance trimming, the tested watersprouts did not appear to have received heading cuts once their growth initiated.

Stress is a measurement of force per unit area and is measured in megapascals (MPa), in which 1 MPa equals 1 Newton per square millimeter (145 pounds per square inch). The watersprout closest to the heading cut was chosen for the test. The strength of a watersprout and branch was measured by applying an increasing load until failure occurred. A 19 mm (0.76 in) double-braid rope was attached to the watersprout/branch, run downward, redirected through an arborist block at the base of the tree and into a winch (Figure 2). To concentrate the load at or near the point of watersprout/branch at-

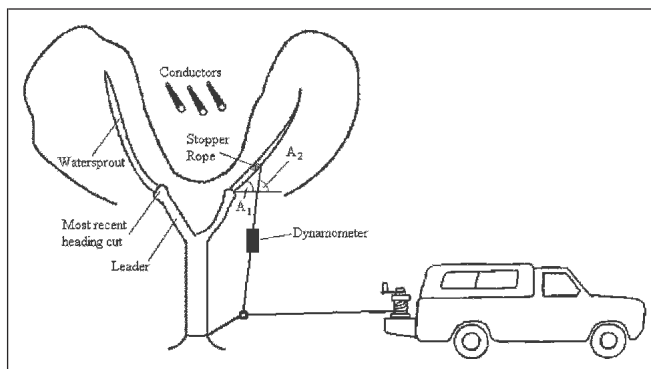


Figure 2. A silver maple tree converted from round-over to a V-trim during electrical line clearance activities depicting a watersprout growing on a parent stem (leader) subjected to a heading cut. Rigging system for watersprout/branch failure testing included a rope, dynamometer with shackles, and winch attached to a pickup truck. Angles A_1 (watersprout/branch angle) and A_2 (rope angle) are measured with 0° parallel to the ground and 90° perpendicular to the ground.

tachment yet allow for the maximum moment arm during pulling, the attachment point for the rope was made as far as possible from each individual branch attachment but not so far as to cause the branch to bend and fail away from the point of attachment. The downward direction of the rope simulated a static load that would be applied during the buildup of snow or ice. An electronic dynamometer was positioned in the rigging system just below the watersprout/branch, thus the dissipation of load in the rope was assumed to be negligible.

The dynamometer was set to record the maximum applied load and the winch was cranked to apply a steadily increasing load until failure occurred. Postfailure measurements included: load at failure, diameter at the point of failure, diameter of decay at failure, distance from the failure to the point of branch attachment, and the distance from the applied load to the failure (L) or moment arm (Figure 3).

The weights of the dynamometer, shackles, rope, and arborist block were added to the load measured during the pulling exercise to determine applied force (P). Force is a vector quantity that includes a magnitude and a directional component. In these exercises, both the branch (A_1) and rope (A_2) angles affected the applied force and equations 1 and 2 were used to convert the applied force into P_y (bending or downward) and P_x (axial) forces (Figure 3). All angles were measured with respect to zero being parallel to the ground.

Equation 1: Converting applied force into bending force.

$$P_y = \sin(A_2 - A_1) \times P$$

Equation 2: Converting applied force into axial force.

$$P_x = \cos(A_2 - A_1) \times P$$



Figure 1. A silver maple tree converted from a round-over to a V-trim during electrical line clearance.

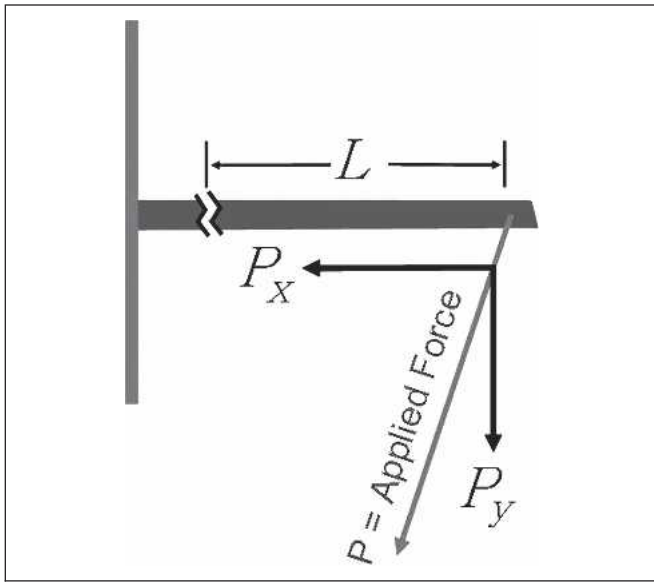


Figure 3. Applied force (*P*) converted into axial force (*P_x*) and bending force (*P_y*); also shown is the moment arm (*L*).

Stress at failure was calculated using the engineering formula for normal stress in cantilevered beams (Hibbler 1997) shown in equation 3. This formula accounts for both axial and bending force effects resulting from the applied load. Another possible source of stress from the applied load, torsion, was not considered in this work. A bowline knot was loosely tied around the branch and no twisting movements occurred during the exercises; thus, the dead loading was assumed not to induce torsion. To prevent the rope from sliding down the limb during the exercise, a 13 mm (0.52 in) stopper rope was tied with a minimum of seven wraps around the branch just below the rope holding the dynamometer.

Equation 3: Normal stress equation for tensile failures along the branch or point of attachment.

$$\text{Stress} = \frac{-P_x}{\pi r^2} + \frac{P_y(L)Y}{\frac{1}{4} \pi r^4}$$

Where

- L* = failure moment arm
- P_x* = axial force
- P_y* = bending force
- r* = radius at failure
- Y* = distance from center point to failure

A knife was used as a probe to determine the extent of internal decay in the cross-section of the failure. The area of decayed wood was subtracted from the branch cross-sectional area ($\pi r^2_{\text{branch}} - \pi r^2_{\text{decay}}$) before being used in the denominator of the first term in equation 3. Decay was also sub-

tracted from the moment of inertia ($\frac{1}{4}\pi r^4_{\text{branch}} - \frac{1}{4}\pi r^4_{\text{decay}}$) before this value was used in the second term of this formula.

Diameter at the point of attachment was measured for the entire population of watersprouts (consisting of watersprouts sampled during pulling exercises and those remaining afterward). The presence of decay at the point of attachment for the entire watersprouts population was noted by visual inspection.

Analysis of variance and Tukey’s studentized range procedures were used to determine the differences between the mean failure stress values. Regression analysis was used to determine linear relationships in the data. All statistical analyses were run using SAS System version 8.2 (SAS 2001) and significance levels were set at 5% ($\alpha = 0.05$).

RESULTS

Six converted trees were sampled with diameters at breast height (DBH) (137.2 cm [54.9 in]) ranging from 34 to 71 cm (13.6 to 28.4 in). Thirty-nine watersprouts (diameter 2.1 to 21 cm [0.8 to 8.4 in]) and 15 control branches (diameter 4.5 to 14.2 cm [1.8 to 5.7 in]) were sampled during the testing. Historical trim records were not available for the converted trees; hence, the number of previous round-over trims was not determined. Although growth rings were not counted in either watersprouts or control branches, the watersprouts were considered relatively young in the conversion process from round-over trimming to V-trimming, potentially two to three trim cycles (6 to 12 years). The five control trees were sampled ranged in DBH from 20 to 33.2 cm (8 to 13.3 in).

Table 1 reviews the pattern of failure locations previously reported by this author (Dahle et al. 2006). The 38 failures that occurred at point of attachment (POA) or within two diameter lengths of POA were separated into three groups of 13 control branches, 12 watersprouts with no decay at the point of failure and 13 watersprouts with decay at the point of failure.

Table 1. Percent of failures occurring in each region for control branches and watersprouts in silver maple trees converted from round-over to V-trim during electrical line clearance operations.

Treatment	No failure (%)	Beyond POA ^z (%)	At POA ^y (%)	Near POA ^x (%)	Leader (%)
Control	7	7	33	53	0
Watersprout	8	8	33	31	21

^zBeyond POA = failure occurred along the branch/watersprout and further than two diameter lengths from the point of attachment (POA).

^yAt POA = failure occurred at the point of attachment of branch/watersprout to parent stem (leader).

^xNear POA = failure occurred along the branch/watersprout but within two diameter lengths from the point of attachment.

Leader = main leader broke before watersprout.

The table is adapted from a previous publication by the author (Dahle et al. 2006).

A significant difference was found between stress at failure and the three treatments ($P < 0.001$). Stress at failure for control branches (35.2 MPa [5,105 lb/in²]) was found to differ from watersprouts with decay (22.4 MPa [3,249 lb/in²]) and watersprouts without decay (13.7 MPa [1987 lb/in²]), yet no significant difference was found between the two watersprout treatments. The watersprouts were then pooled (17.9 MPa [2596 lb/in²]), and a significant difference was found between controls and watersprouts.

There was no significant relationship between stress at failure and diameter at the point of failure in control branches ($P = 0.060$). However, there was a significant relationship between stress at failure and diameter at the point of failure for watersprouts ($P = 0.010$); stress decreased with failure diameter (Figure 4). A highly significant relationship was identified between stress at failure and percent diameter decay (diameter decay at failure/diameter watersprout at failure) ($P = 0.008$) (Figure 5).

Internal decay was present at the point of failure in 52% (13) of the watersprouts tested for strength, and a χ^2 test determined that this was significantly different from the control branches that did not show decay ($P = 0.001$). Internal decay was present in 31% (45) of the entire population of 145 watersprouts. Figure 6 shows the percent of watersprouts with decay in each 2 cm diameter class for the entire watersprout population.

DISCUSSION

The number of failures at the point of attachment was similar between the control branches and watersprouts, except 20% of the watersprout failures occurred along the leader or parent stem (Table 1). This pattern suggests that trees converted from round-over to V-trims will have an increased likelihood of leader failure. This should raise concern in utility arbori-

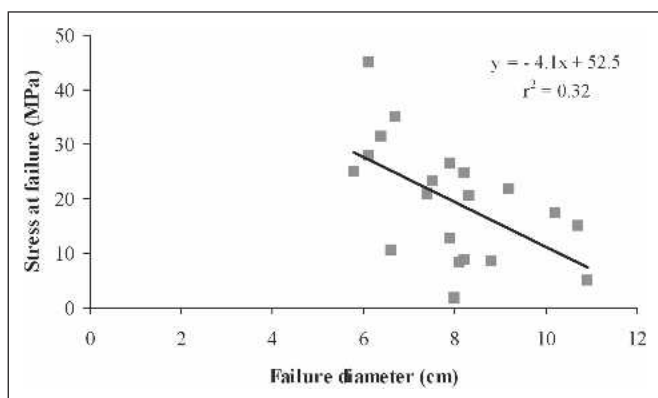


Figure 4. Stress at failure (MPa) versus diameter at failure (cm) in watersprouts of silver maple trees converted from round-over to V-trim during electrical line clearance operations ($P = 0.010$).

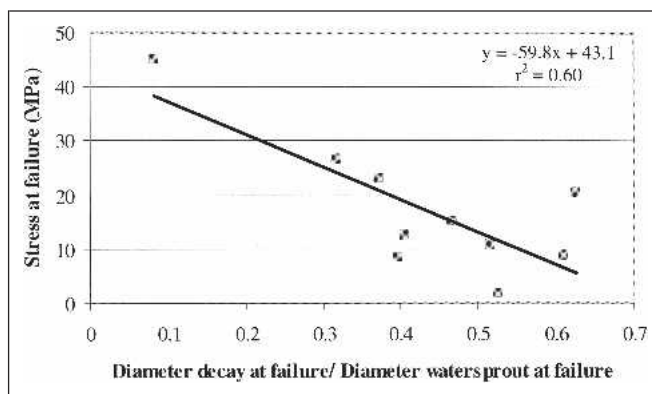


Figure 5. Stress at failure (MPa) versus diameter of decay at failure/diameter of the watersprout at the point of failure for silver maple trees converted from round-over to V-trim during electrical line clearance operations ($P = 0.008$).

culture, because failures along the leaders will lead to larger amounts of wood falling from the tree, increasing the risk of damage to nearby targets.

Two limitations to the stress values presented in this research are 1) the presence of self-loading in the branches/watersprouts and 2) whether the cross-sections (measured in terms of diameter) were circular or elliptical. Self-loading refers to the distributed weight of the branch acting as a “permanent” loading on the branch. In this research, self-loading was not considered an important factor in the amount of external force required to cause failure. The moment of inertia (a geometric shape property that affects resistance to bending) is slightly different for circles and ellipses. Although a few cross-sections may have been ellipses, it was

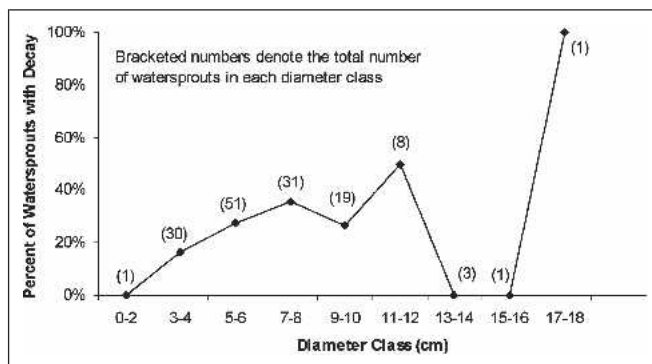


Figure 6. The percentage of watersprouts with decay in each 2-cm diameter class for the entire watersprout population in silver maple trees converted from round-over to V-trim during electrical line clearance operations. The entire population consisted of all watersprouts present on the trees, including those that were and were not sampled during pulling exercises.

judged that the differences were minimal and all cross-sections were considered circular.

The control branches in this study had a failure stress value of 35.2 MPa (5,105 lb/in²), which is similar to the modulus of rupture, a measurement of stress, reported by the U.S. Forest Products Laboratory (1999) of 40 MPa (5,800 lb/in²) for green silver maple wood. This comparison suggests that branch wood has a strength property similar to trunk wood. Watersprouts were found to be 49% weaker than naturally occurring branches, confirming that silver maple watersprouts are weaker than natural branches.

Because stress is a measurement of force per unit area, it is not surprising that stress did not vary with diameter in the control branches. As the area of wood increased, the force required to break the branch increased proportionally. However, for watersprouts, stress at failure decreased as diameter increased (Figure 4). This is most likely the result of a combination of the inherent weak nature of watersprouts and the greater likelihood of decay in larger (and thus older) watersprouts (Figure 6). Although the amount of decay was accounted for when calculating stress (the cross-sectional area of decay and moment of inertia of decay were removed), this may not fully account for the presence of decay. A probe was used to identify the extent of decay and it may be that the amount of decay in the wood matrix was underestimated, further reducing the amount of sound wood present.

Additionally, stress at failure decreased as the ratio of decayed wood:branch diameter increased in the watersprouts (Figure 5), suggesting that the presence of decay is correlated with strength loss. It may be that the nature of the failure changes as the size of the decay column increases. In a solid branch, the failure typically begins with outward compressive buckling on the lower side followed by tensile failure on the top. The possibility of compressive buckling becomes greater as the decay fungi invade the remaining wood matrix on the outer portions of the watersprout. Additional research is needed to determine the influence of decay on the strength property of the wood matrix.

The presence of decay is often considered a likely consequence of heading cuts; indeed, Dahle et al. (2006) previously reported that 90% of silver maple leader with heading cuts contained decay. This study found internal decay in 52% of the watersprout failures and in none of the control branches. Internal decay occurred in 28% of the entire watersprout population. This contrasts with Gilman and Knox (2005) who did not see decay in crape myrtle (*Lagerstroemia* × 'Natchez') sprouts arising after heading cuts. Silver maple heartwood is considered a poor compartmentalizer (Giles 2001), whereas Gilman and Knox (2005) suggest that that 'Natchez' crape myrtle is good. It is likely that decay in these silver maples originated in the leader at or near the location of the heading cut, breached barrier walls, and moved into the watersprouts. If decay can move into rapidly growing water-

sprouts with large growth rings, it is likely to spread rapidly. Thus, less force will be required to induce failure in watersprouts, further reducing their weak nature. Additional research is needed to determine the mode of action for decay movement from leaders into watersprouts.

IMPLICATIONS

The information presented here should aid utility arborists in making better informed decisions about the risk factors in the trees they manage. The conversion from round-over trimming to V-trimming does appear to predispose trees to failures. Watersprouts were found to be 49% weaker than naturally occurring silver maple branches and strength appeared to decrease as the watersprouts grew in size. Utility arborists should examine their trees for the presence of decay when considering whether a tree is at risk of failure, especially when larger watersprouts are present. Managers may want to consider the long-term consequences of converting from round-over pruning to V-pruning and decide if other actions are appropriate, including the removal of trees subjected to multiple cycles of round-overs.

This information is not limited to utility arboriculture. Many trees in urban areas suffer from topping. All arborists should be concerned with the negative aspects of topping. These data suggest that management alternatives might be limited after silver maples are topped, particularly when decay is present in the leaders.

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Résumé. Les arbres dont l'élagage se faisait à l'origine en fonction d'une forme globulaire et qui ont été convertis vers un élagage en «V» peuvent développer au niveau de leur cime des gourmands potentiellement fragile au bris, et ce à partir de branches-mères, avec une grande probabilité de carie. Cette étude a été menée pour déterminer si la conversion de la forme d'élagage, depuis celle globulaire vers celle en «V», prédispose l'érable argenté (*Acer saccharinum* L.) aux bris et si la carie risque plus de se produire au niveau des gourmands qui se forment après des coupes de réduction par rapport à des branches qui se forment à partir de bourgeons latéraux. Les gourmands étaient mécaniquement rejetés vers l'extérieur chez les arbres convertis et étaient généralement considérés comme étant 49% plus faibles que les branches qui se formaient de manière normale. La force de la branche au point d'attache des gourmands diminuait avec l'accroissement en dimension des gourmands et la carie était présente dans plus de la moitié des gourmands au niveau de leur point d'attache. La conversion de l'élagage depuis la forme globulaire vers celle en «V» apparaît prédisposer les érables argentés à des risques plus élevés de bris.

Zusammenfassung. Bäume, die von einer runden Krone auf eine V-förmige Krone zurück geschnitten werden, können eine Krone mit potentiell schwachen Wasserreisern entwickeln, die am Hauptstamm entstehen und sehr anfällig für Fäulnis sind. Diese Studie

wurde durchgeführt, um zu bestimmen, ob Silberahorne durch die Kronenumformung von rund auf V-förmig fäulnisanfälliger werden und ob diese Fäule mehr in den Wassertrieben oder in den aus lateralen Knospen entwickelten Treiben entsteht. Die Wassertriebe der umgeformten Bäume wurden mechanisch gezogen und waren 49 % schwächer als die Triebe an normal entwickelten Bäumen. Die Aststärke bei Versagen nahm mit zunehmender Stärke der Wassertriebe ab. Die Umformung von einer runden zu einer V-förmigen Krone scheint die Silberahorne eher für Fäulnis und Baumversagen anfällig zu machen.

Resumen. Los árboles convertidos de forma redondeada a forma de V podrían desarrollar una copa de brotes potencialmente débiles en ramas parentales con alta probabilidad de descomposición. Este estudio fue llevado a cabo para determinar si la conversión predispone al maple (*Acer saccharinum* L.) a fallar, y si el decaimiento es más propenso a ocurrir en los rebrotes resultantes después de las cortas de despunte en ramas laterales. Los rebrotes fueron tensados mecánicamente y se encontró que eran 49% más débiles que los de las ramas normales sin cortar. La resistencia de la rama a fallar (stress) disminuyó a medida que los rebrotes crecieron en tamaño, y el decaimiento estuvo presente en más de la mitad del rebrotes en el punto de falla. La conversión de forma redondeada a forma de V parece predisponer a la falla a los árboles de maple.