COMPARISON OF BRANCH FAILURE DURING STATIC LOADING OF SILVER AND NORWAY MAPLES[1,2]

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Abstract. Trees in the urban setting can be a hazard to utility lines, structures, traffic flow and pedestrians. Identifying characteristics that make limbs prone to failure could help save money and lives. The purpose of this study was to determine the effects of branch angle, form, and wood specific gravity on susceptibility to failure during static loading. Branches of silver (*Acer saccharinum*) and Norway (*Acer platanoides*) maple were mechanically broken. Forces causing failure were measured. No correlation was found between bending stress and branch angle or wood specific gravity. Silver and Norway maples were similar in susceptibility to failure.

Trees are an important part of our city and suburban environments. However, trees in the urban setting can present added costs and liabilities. Utility companies in the United States spend hundreds of millions of dollars each year to trim trees in an attempt to protect lines. City foresters frequently must dispatch crews to remove fallen limbs that are blocking traffic or interfering with city services. Personal injury or death also results from tree failures. Identification of hazardous branches is becoming an important part of an urban forester's job. If unsafe branches can be identified and corrected or removed, subsequent damage will be reduced.

Storm damage to trees can be divided into two categories. The dynamic force of the wind may whip trees back and forth or twist them before branches or trunks fail. Snow or ice loading of the limbs is primarily a static force. Weight accumulates on the limb until, in some cases, the branch breaks.

Susceptibility of limbs to damage from an increased load of ice or snow depends on various factors. Genetic differences among species influence wood strength or structural stability of the branch attachment (1,8,9). The size of the limb in relation to the size of the trunk or branch from which it originates could be a major factor in susceptibility to breakage (4,6). The angle of branch attachment may also be important (5,7,11). Wood specific gravity may also affect the branch strength (2).

This study simulated the static load which is generated naturally by ice or snow on a branch. The relationship between the force required to cause branch failure and branch size, specific gravity, crotch angle and species were examined. The objective was to identify which factors predict resistance or susceptibility of limbs to failure under increased loads.

Materials and Methods

Two maple species, silver maple (*Acer saccharinum*) and Norway maple (*Acer platanoides*), were chosen for this study. These two species typically make up about half of the mature urban tree population in Ohio. Silver maple has a reputation for being weak-wooded, with poor crotches and prone to storm damage (3,12). Norway maple is thought by many to be a superior tree, with stronger wood and a more stable structure (12).

Four silver maples and three Norway maples were used in this study. All were park trees, approximately 75 cm (30 inches) in diameter and containing no more than l0% deadwood. Forty live branches of each species, ranging from 5-30 cm (2-12 in) diameter were broken.

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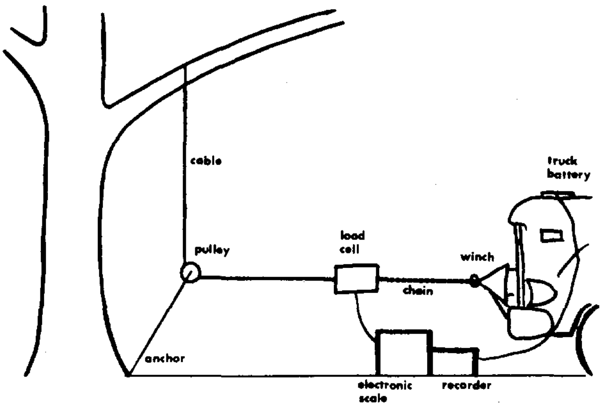

Figure 1. Apparatus for static loading of tree branches. The truck battery was the power source for the equipment.

Branch and trunk diameter and crotch angle were measured. Limbs that showed any signs of decay, cracks or other flaws were rejected.

A 1 cm (3/8 inch) diameter cable was attached to the limb that was to be broken. The cable was wrapped around the limb and hooked upon itself. The distance from the crotch to the point of cable attachment was measured. An aerial lift truck was used to attach the cable, take measurements and photograph the limbs.

The system for pulling the limbs was designed to ensure that the pulling force was vertical to the ground. The cable came down vertically from the branch and around a 2.7 metric ton(3 ton), 20 cm (8 inch) snatch block pulley. The pulley was anchored at the tree base with 0.6 cm (l/4 inch), heavy duty chains and a 1.8 metric ton (2 ton) capacity come-along. The come-along was used to let the pulley in and out to keep the pull vertical (Figure l).

The cable was pulled by a truck mounted winch. A Censortronics 2.5 metric ton (10,000 lb) load cell was attached between the pulling cable and the winch cable. The load cell was connected to an Electroscale Model 533 weightmeter which gave a digital readout of the applied force, which was recorded by an inline Linear Model 8377-l5 recorder. A converter was built to make the weightmeter and recorder compatible. The electronic equipment was powered by the truck battery via a Tripplite DC to AC Model PV-200 power invertor.

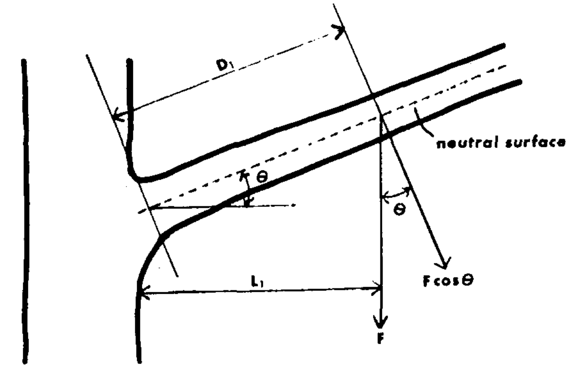

Figure 2. Diagram showing the parameters used to calculate the bending stress when a branch broke at the crotch. F represents the external force applied.

The cable was pulled very slowly with the winch to provide a gradual increase of the static load on a branch. When the branch failed, the maximum force applied was recorded. The branch diameter and distance from the failure point to the loading point were recorded. Whether failure occurred at the crotch or along the branch was noted. The limb was examined for flaws, decay, or included bark at the crotch. Wood samples were taken for determination of specific gravity (gm/cm^3).

Calculations of bending stress were based on a cylindrical wood beam (13). If the branch broke at the crotch (Figure 2), the bending stress was calculated using Equation 1 and expressed in Newtons per square centimeter (N/cm^2). If the branch broke somewhere along the limb (Figure

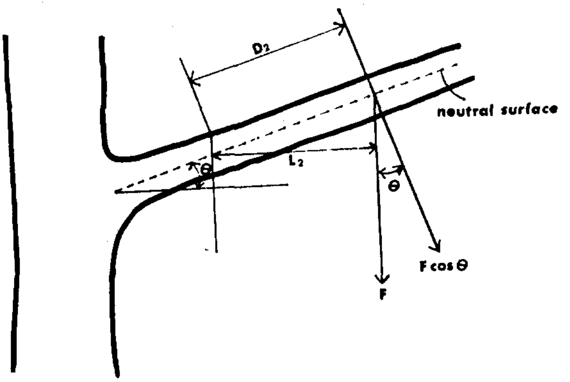

Figure 3. Diagram showing the parameters used to calculate the bending stress when a branch failed between the crotch and the loading point. F represents the external force applied.

3), the bending stress was calculated in N/cm^2 using Equation 2.

Equation 1:

$$S_b = M_c / I = F \cos\theta \times D_1 \times r \;/\; [\pi r^4/4]$$
$$= [F \cos\theta \times L_1] / [\cos\theta \times r] / [\pi r^4/4]$$
$$= 4 F L_1 / \pi r^3$$

Where:

S_b = bending stress at crotch
M = moment
c = branch radius at the crotch
I = area moment of inertia of branch
F = external force applied
L_1 = the horizontal distance from the crotch to the loading point.
D1 = the branch length from the crotch to the loading point.
r = radius of the branch at the breaking point
θ = angle between neutral surface and horizontal

Equation 2:

$$S_b = 4 F L_2 / \pi r^3$$

Where:

S_b = bending stress
F = external force applied
L_2 = the horizontal distance from the breaking point to the loading point.
r = the branch radius at the breaking point.

Results and Discussion

Data for the two species of maples were analyzed and compared. Differences between means were tested using the least significant difference (LSD) technique. Mean crotch angles, bending stress, and the moment at breaking point were not found to be significantly different between the species. The wood of Norway maple was significantly denser than the wood of silver maple (0.62 vs 0.52 gm/cm3), respectively (Table 1).

Analyses of variance were performed on the same characteristics using species, position of break and the interaction as independent variables with crotch angle as the dependent variable. The species-breaking point interaction was highly significant. When bending stress was the dependent variable, the position of break was highly significant.

The fact that the mean crotch angles for silver and Norway maple were not different is interesting and counter to the commonly held beliefs of many people. An informal check of street trees in Columbus, Ohio supported our findings. The largest branches of silver maple, often had the narrowest crotches and were too large to be broken using this technique. Large co-dominant branches were also few in number relative to the number of branches in the tree.

The lack of significance between the means for bending stress and moment for the two species is important. Despite the differences in wood density, silver and Norway maples are equally tolerant of loading if there are no defects in the limbs. There does appear to be some difference between silver maple and Norway maple in resistance to failure under loading conditions as reflected in the position of failure.

The position of failure, at the crotch or along the limb, appeared both in the correlations and analysis of variance. In silver maple, the wider crotches tended to be less stable than the narrow crotches. In Norway maple, branches with wide angles of attachment tended to fail along the branch while narrow crotches more frequently failed at the crotch. Of the limbs that failed at the crotch, none

Table 1. Mean comparisons between silver and Norway maple at branch failure.

Species	Crotch angle* (degree)	Specific gravity (gm/cm^3)	Bending stress ($newtons/cm^2$)	Moment (newton meters)
Silver maple	56.7 a	0.52 a	2970 a	3009 a
Norway maple	62.6 a	0.62 b	2451 a	3521 a
LSD (0.05)	8.5	0.02	881	1842

Means in columns followed by the same letter are not significantly different.
* Mean crotch angles for this study may not be representative over the species since large limbs could not be broken with the technique employed.

contained bark inclusions or decay in either species.

Summary

No significant difference was found in bending stress or moment between the two species under static loads which would simulate snow and ice loads. Although the specific gravity of Norway maple is greater than that of silver, this study indicated that it did not make Norway maple more storm resistant. No correlations between specific gravity and moment or specific gravity and bending stress were found. Norway maple has a reputation for being stronger and more structurally stable than silver maple. However, nothing in this study supports that claim.

For years, students of arboriculture have been taught that narrow branch angles are not desirable since they are more likely to break. Silver maple has a bad reputation due in part, to its "poor crotches." This study found nothing to support either of these claims for branch angles with no inclusions. In the absence of bark inclusions, narrow crotch angles may be no less stable than wide crotches. Also, branches of silver maple do not appear to be more prone to breaking under load than those of Norway maple.

Literature Cited

1. Butler, J. D. and B. T. Swanson. 1974. *How snow, ice injury affects different trees.* Grounds Maintenance 9(10):29-30, 40.
2. Esser, M. H. M. 1946. *Tree trunks and branches as optimum mechanical supports of the crown: II. The branches.* Bulletin of Mathematical Biophysics 8:95-100.
3. Hightshoe, G. M. 1988. Native Trees Shrubs and Vines for Urban and Rural America. Van Nostrand Reinhold Press, New York, 819 pp.
4. MacDaniels, L. H. 1932. *Factors affecting the breaking strength of apple tree crotches.* Proc. of Am. Soc. for Hort. Sci. 29:44.
5. MacDaniels, L. H. 1923. The apple tree crotch. Cornell University Agricultural Experiment Station Bulletin 419, pp. 1-22.
6. McMahon, T. A. 1975. *The mechanical design of trees.* Scientific American, July 1975, pp. 92-102.
7. Miller, V. J. 1959. *Crotch influence on strength and breaking point of apple tree branches.* Proc. Am. Soc. for Hort. Sci. 73:23-32.
8. Opatowski, I. 1944. On the form and strength of trees: Part II. The primary branches. Bulletin of Mathematical Biophysics 6:153-156.
9. Opatowski, I. 1945. On the form and strength of trees: Part III. The secondary branches and their relation to the primary branches. Bulletin of Mathematical Biophysics 7:1-4.
10. Salisbury, F. B. and C. W. Ross. 1978. Plant Physiology, Wadsworth Publishing Company, CA. pp. 366-367.
11. Shigo, A. L. 1985. *How tree branches are attached to trunks.* Can. J. Bot. 63:(8)1391-1401.
12. Wyman, D. 1965. Trees for American Gardens. MacMillan Company, New York, 501 pp.
13. Yan, Shan-Shan. 1982. Effects of ice and mechanical loads for three species of trees. Master's Thesis. The Ohio State University, Columbus, Ohio, 59 pp.

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Résumé. Cette étude cherche à déterminer les effets de l'angle d'insertion de la branche, du type de bois et du poids sur la susceptibilité d'une branche à se casser et tomber lors de surcharges statiques. Les branches d'érables argenté et de Norvège ont été cassées mécaniquement. Les forces impliquées causant le bris ont été mesurées. Aucune corrélation n'a été découverte entre le stress causé sur la courbure de la branche et son angle d'attache ou son poids. Les érables argenté (*Acer saccharinum*) et de Norvège (*Acer platanoides*) sont similaires quant à leur susceptibilité à se briser.

Zusammenfassung. In dieser Studie wurden die Einflüsse von Astwinkel, Form und holzartspezifische Schwere bestimmt, um die Anfälligkeit für Versagen während stetiger Belastung zu untersuchen. Silber- und Bergahornäste wurden dafür mechanisch gebrochen. Die erforderlichen Kräfte zum Brechen der Äste wurden gemessen. Man fand keine Korrelation zwischen dem Biegeaufwand und dem Astwinkel noch der holzspezifischen Schwere.