Likelihood of Tree Failure from Root and Sapwood Cutting

E. Thomas Smiley, Ph.D.
Bartlett Tree Research Laboratories
Charlotte, NC
Clemson University, SC

What is going on with Tree Risk Assessment ?

- ISO 31000 & 31010 Risk Mgmt & Assessment – finished 2009
- ANSI A300 Standard – finished 2010
- ISA BMP for Risk Assessment – 2011
- ISA Tree Risk Qualification –2013

ISA International Society of Arboriculture

Tree Risk Assessment Qualification

TRAQ Course objectives:

The Tree Risk Assessment qualified professional will:

- be proficient with the fundamentals of basic tree risk assessment.
- be able to gather and synthesize information needed to assess tree risk.
- make reasoned judgments and recommendations for mitigating identified risk.

TRAQ Class Details

Prerequisites – ISA Cert Arborist or other

Lecture, Indoor and Outdoor Activities

- Introduction to Tree Risk Assessment
- Levels of Assessment
- Target and Site Assessment
- Tree Biology and Mechanics
- Tree Inspection and Assessment
- Data Analysis and Risk Categorization
- Mitigation
- Reporting

Total class time 2 Days

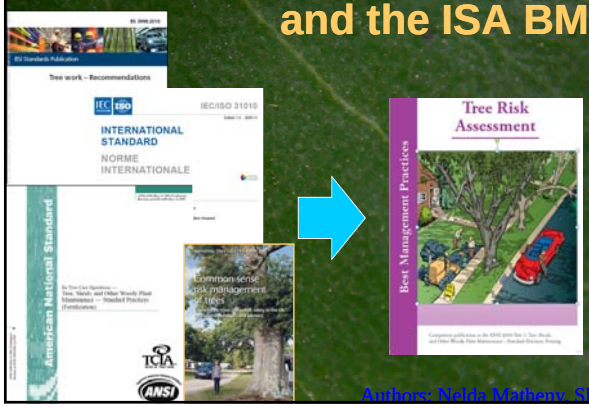
Exam – written exam, and outdoor skills test ½ Day

Cost* ISA Member $625, Nonmember $750

Upon Completion of TRAQ

No Recertification
Requalification after 5 years

TRAQ is based on Standards and the ISA BMP



Authors: Nelda Matheny, Sharo

ISA BMP categorizes Risk using two matrices:

Likelihood of Failure	Likelihood of Impacting Target			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very Likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Table 1: Likelihood matrix -likelihood of the event occurring

Likelihood of Failure & Impact	Consequences of Tree Failure			
	Negligible	Minor	Significant	Severe
Very Likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Table 2: Risk matrix -categorizing tree risk

Three Levels of Tree Risk Assessment

Level 1, Limited Visual

Level 2, Basic

Level 3, Advanced

All looking at factors that affect the likelihood and consequences of tree failure.

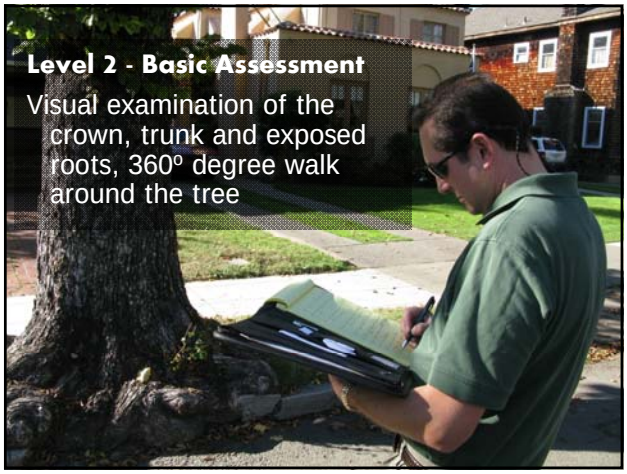
Level 1, Limited Visual Assessment

A rapid assessment of a tree populations looking for trees with serious defects.

Options:
Drive-by
Walk-by
Fly-over

Level 2 - Basic Assessment

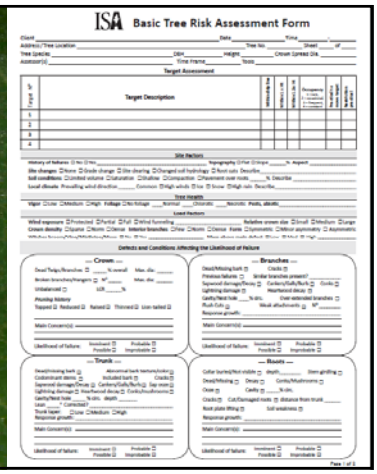
Visual examination of the crown, trunk and exposed roots, 360º degree walk around the tree

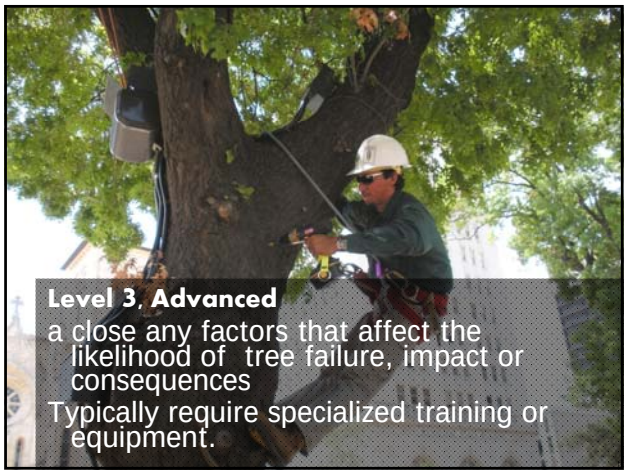


Basic Assessment

may include use of binoculars, mallet, probe or trowel.

ISA Datasheet for Basic Assessments





Level 3, Advanced

a close any factors that affect the likelihood of tree failure, impact or consequences

Typically require specialized training or equipment.

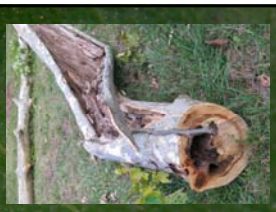
Part 1. Sapwood loss and implications for tree stability

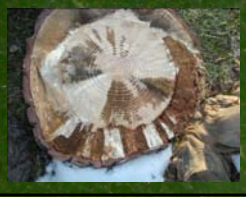
Research project conducted in part at the ISA/TREE Fund Biomechanics Week (2010) with Dr. Brian Kane

Missing wood contributes to tree failures, most research has focused on internal decay

It is generally accepted that up to 2/3 of the interior of the stem can be lost without affecting stability

However, wood can also be absent from the outer portion of the tree





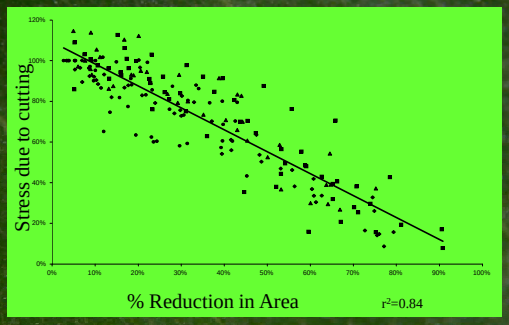
Cutting notches and pulling testing with measured force to determine the effects of sapwood loss on stability

Research Methods

Species: Red maple *(Acer rubrum)*
Sweetgum *(Liquidambar styraciflua)*
Sawtooth oak *(Quercus acutissima)*

Size: *3 to 10* inches DBH
Number of trees: *45*
Number of cuts: *188*

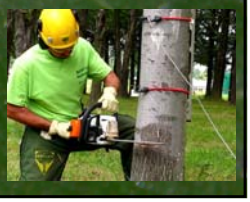
Relationship between Area of a Sapwood Cut and Stress



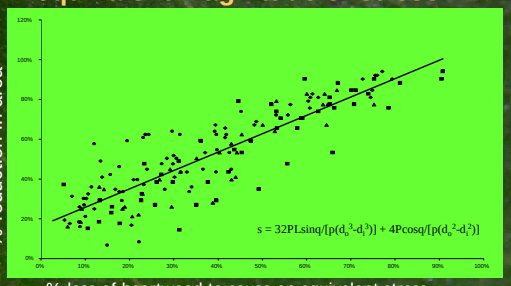
small red maple (■), large red maple (●), sweetgum (▲), and sawtooth oak ♦). The relationship ($\Delta\sigma$ = 1.10 - 1.08 * ΔA) was significant ($p < 0.001$), robust (r^2 = 0.84) and similar for all species (p = 0.258).

Strong correlations between both cross sectional of cut and stability of the tree. Minor differences among species.

How much loss is too much?



Relationship between the reduction in sapwood and the heartwood to cause an equivalent magnitude of stress



Small red maple (■), large red maple (●), sweetgum (▲), and sawtooth oak ♦). The relationship ($\Delta\sigma_C$ = 0.17 + 0.92 * ΔA) was significant ($p < 0.001$), robust (r^2 = 0.76), and similar for all species (p = 0.740).

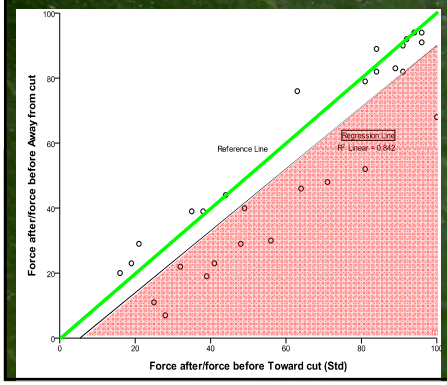
Sapwood loss decreases stress about twice as much as heartwood loss

The generally accepted maximum amount of allowable concentric heartwood loss is 2/3 of cross section,

So the maximum amount of sapwood loss is about **1/3**

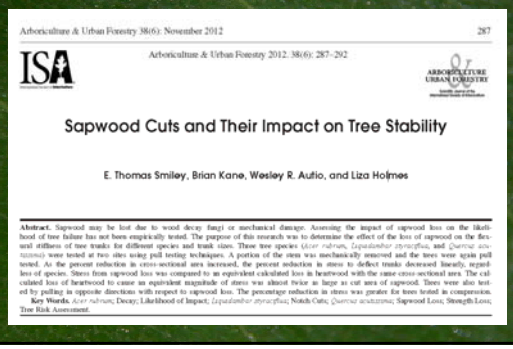
Likelihood of Impact
Which direction is the tree more likely to fail?

Likelihood of Impact
Which direction is the tree more likely to fail?



Failure is more likely to be in toward the cut.
But wind direction is probably more important

For all of the details


Arboriculture & Urban Forestry 38(6): November 2012 287

ISA

Arboriculture & Urban Forestry 2012. 38(6): 287–292

Sapwood Cuts and Their Impact on Tree Stability

E. Thomas Smiley, Brian Kane, Wesley R. Autio, and Liza Holmes

Abstract. Sapwood may be lost due to wood decay, fungi or mechanical damage. Assessing the impact of sapwood loss on the likelihood of tree failure has not been empirically tested. The purpose of this research was to determine the effect of the loss of sapwood on the flexural stiffness of tree trunks for different species and trunk sizes. Three tree species (*Acer rubrum*, *Liquidambar styraciflua*, and *Quercus acutissima*) were tested at two sites using pull testing techniques. A portion of the stem was mechanically removed and the trees were again pull tested. As the percent reduction in cross-sectional area increased, the percent reduction in stress to deflect trunks decreased linearly, regardless of species. Stress from sapwood loss was compared to an equivalent calculated loss in heartwood with the same cross-sectional area. The calculated loss of heartwood to cause an equivalent magnitude of stress was almost twice as large as cut area of sapwood. Trees were also tested by pulling in opposite directions with respect to sapwood loss. The percentage reduction in stress was greater for trees tested in compression.

Key Words. *Acer rubrum*; Decay; Likelihood of Impact; *Liquidambar styraciflua*; Notch Cuts; *Quercus acutissima*; Sapwood Loss; Strength Loss; Tree Risk Assessment.

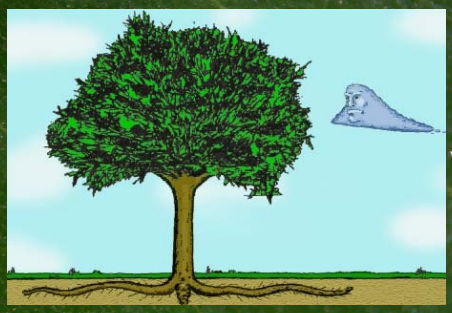
Part 2. Assessing tree roots and root damage

How many failures are Root Related?

% of Failures reported	Singapore 10 years	International Tree Failure Database (ITFD)	US Forest Service 1965-1980	
			Conifers	Hardwoods
Branches	70	33	5	10
Trunks	8	32	19	42
Roots	22	35	76	48

How do roots work?

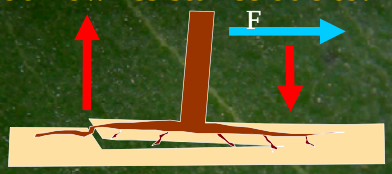
Forces on roots



Types of Failures

Root Failures
Soil Failures

Windthrow resistance due to:



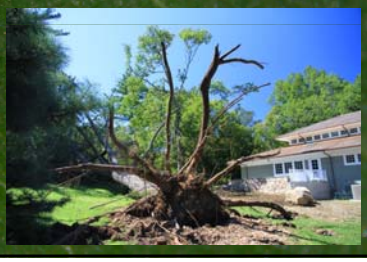
1. Weight of 'root-plate';
2. Root strength on windward side;
3. Root strength on leeward side;
4. Frictional properties of soil- highly moisture dependant.

From: Tim Newson Univ. of Western Ontario

Test your knowledge of tree roots

What is a typical number of buttress roots on a mature tree?

7-11



Test your knowledge of tree roots

What is the relation between trunk cross sectional area (CSA) at DBH and the CSA of the buttress roots?

In our studies on eastern hardwood, the root CSA is **three** times the trunk CSA

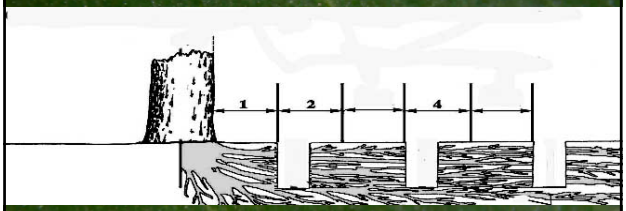
However, trees also have oblique or tap roots

Root cutting research at the Bartlett Lab

1) Linear root cuts – how close can we cut without affecting stability?
2) Individual root cuts at the trunk-
   a. how many roots can we cut?
   b. what is the best way to assess root loss?

Root cuts are common in urban areas

Root Cutting: How close should you get?



Many municipalities allow cutting to the trunk. How close is too close?

Using a Stump Cutter to Severe the Root System of each Tree

Linear Cuts

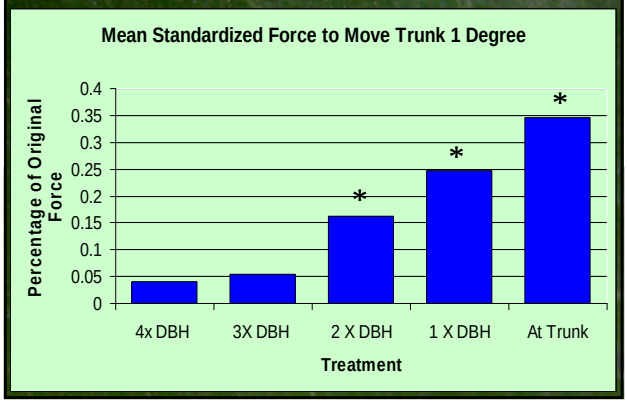
Across the root system

Linear cut close to trunk

Cut at Trunk

Pull testing

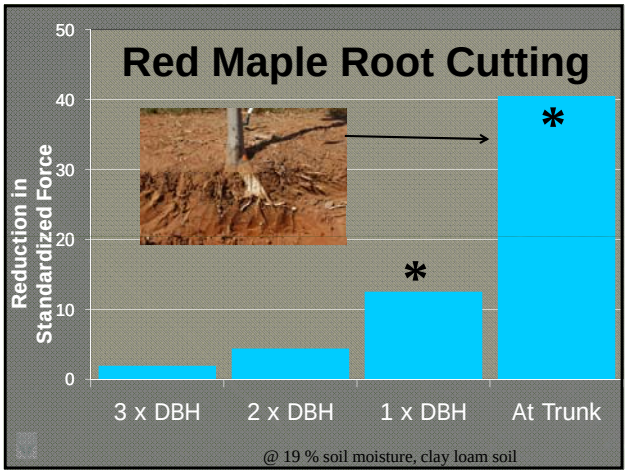
Linear Root Cuts on Willow oak



Repeating the Trial on Red maple

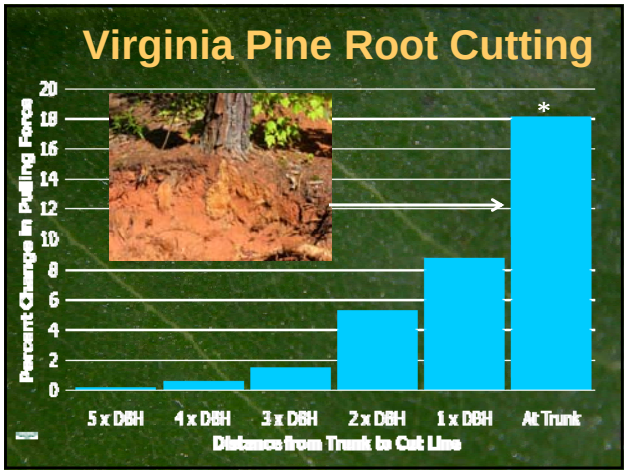
Ave DBH 6.2 cm = 2.4 in
21 feet tall

Red Maple Root Cutting



@ 19 % soil moisture, clay loam soil

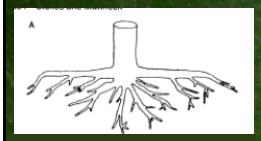
Virginia Pine Root Cutting



Critical cut distances vary with tree species

Tree Species	% Chg in Force at 3xDBH	% Chg in Force at 2xDBH	% Chg in Force at 1xDBH	% Chg in Force at Trunk
Willow Oak	5.5	16*	25*	34*
Red Maple	2	4	12*	40*
Virginia Pine	1.5	5.5	8.5	18*

Are there root system differences among species?



Root System Configurations after Kostler et al. 1968.

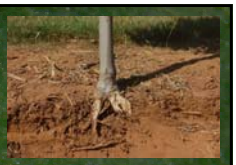
A. Deep root or Heart root system

B. Horizontal, lateral or plate root system

C. Tap root system

Likelihood of Impact: Which way are root cut trees more likely to fall?

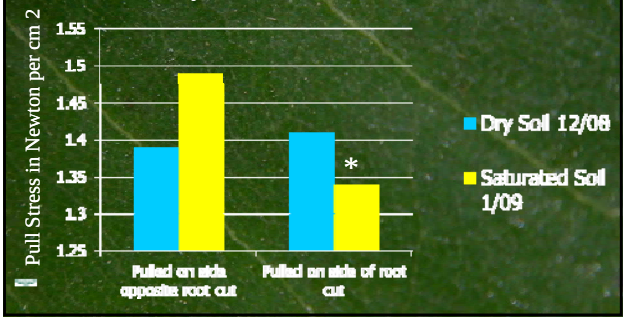
Trees Pulled from Two sides



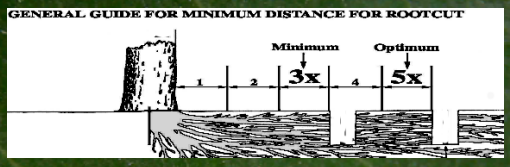
- Pulled away from root cuts
- Pulled toward root cut side
- Pulled trees when the soil was 'dry' 19% moisture (w/w)
- Pulled trees with surface soil was saturated, 36% moisture

Pulling Trees in Saturated Soils

Pull (wind) direction does not affect force when the soil is dry.
Force is significantly different when soil is wet.
Tree more likely to fail toward root cut when wet.



Root Cutting: One side cuts



It is best to keep all cuts outside dripline.
5X DBH is likely to be a sustainable distance for many species. There are significant species differences.
3 X DBH is as close as you should ever recommend.
Within 1to1.5 x DBH consider tree removal
Use greater distances if large tree, leaning trees, trees with root rot etc.

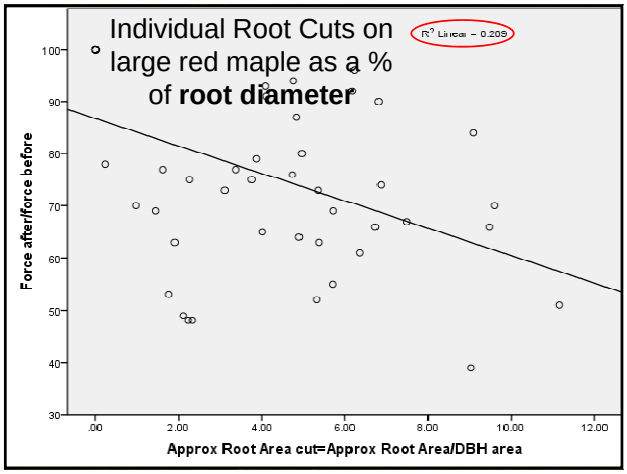
Cutting Individual Roots

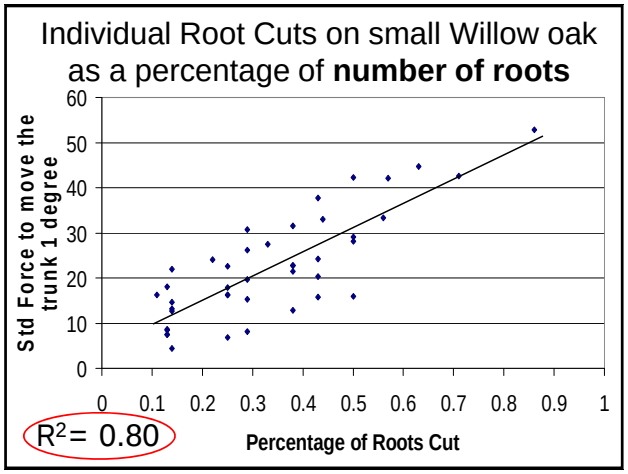
Roots cut on the side opposite of the pull force (tension side)

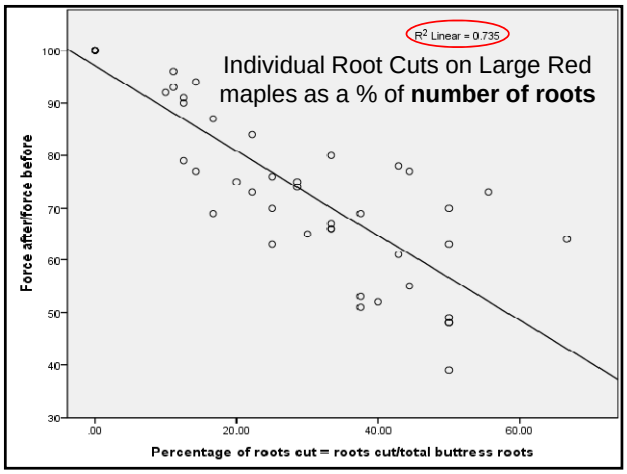
Roots were cut one at a time until roots were severed from 50% of the trunk circumference

When assessing root loss at the trunk, is it better to measure root width (diameter) or a simple root count?

Red Maple with 50% of trunk circumference with roots cut



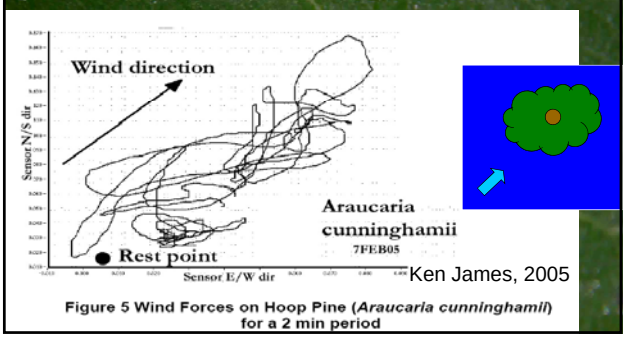




Individual Root Cuts

- Results are highly variable, one root cut can have 5 to 25% change
- Best not to cut any roots at the trunk
- More than 1/3 will significantly increase likelihood of failure

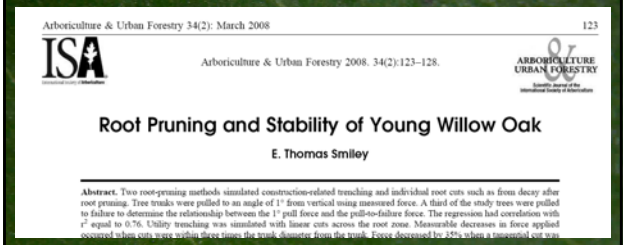
Limitations: 1) We tested with static loads. However, trees experience dynamic loads



2) Trees will compensate for strength loss with response growth over time. We tested immediately after damage.

As with all tree risk assessment, Response growth and Load should be considered in addition to root loss

For more information:


Arboriculture & Urban Forestry 34(2): March 2008 123

ISA

Arboriculture & Urban Forestry 2008. 34(2):123–128.

ARBORICULTURE URBAN FORESTRY

Root Pruning and Stability of Young Willow Oak

E. Thomas Smiley

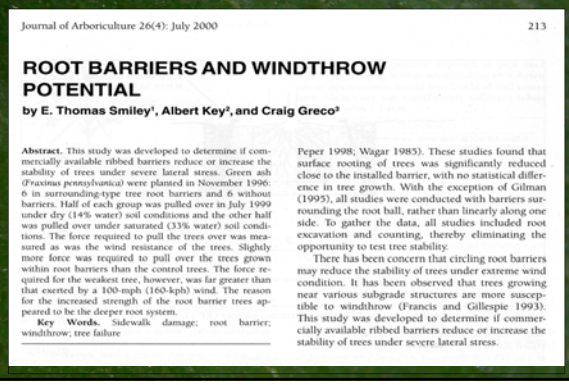
Abstract. Two root-pruning methods simulated construction-related trenching and individual root cuts such as from decay after root pruning. Tree trunks were pulled to an angle of 1° from vertical using measured force. A third of the study trees were pulled to failure to determine the relationship between the 1° pull force and the pull-to-failure force. The regression had correlation with r^2 equal to 0.76. Utility trenching was simulated with linear cuts across the root zone. Measurable decreases in force applied occurred when cuts were within three times the trunk diameter from the trunk. Force decreased by 35% when a tangential cut was

tsmiley@bartlettlab.com

Does Soil Moisture determine where roots break?

- Tested ash trees grown with and without root barriers in wet and dry soil. Pulled to failure.
- Horizontal roots in dry soil breaks occur in the lower stem /root collar
- Oblique roots in dry soil broke in 25-50mm(1 –2 inch) diameter roots
- In Wet soils All broke in 6-12mm (¼ to ½") diameter range

For more information:



Journal of Arboriculture 26(4): July 2000 213

ROOT BARRIERS AND WINDTHROW POTENTIAL

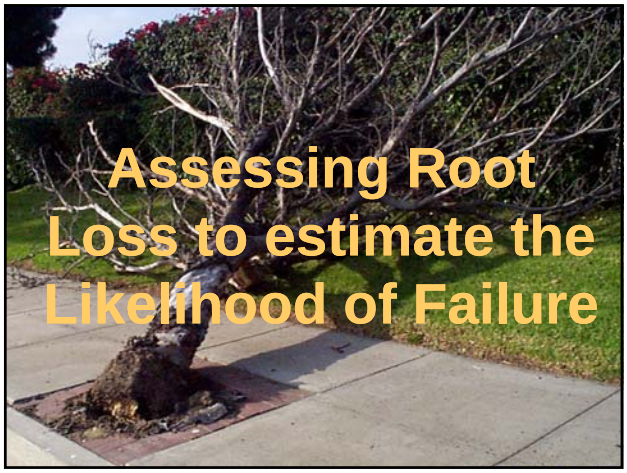
by E. Thomas Smiley[1], Albert Key[2], and Craig Greco[3]

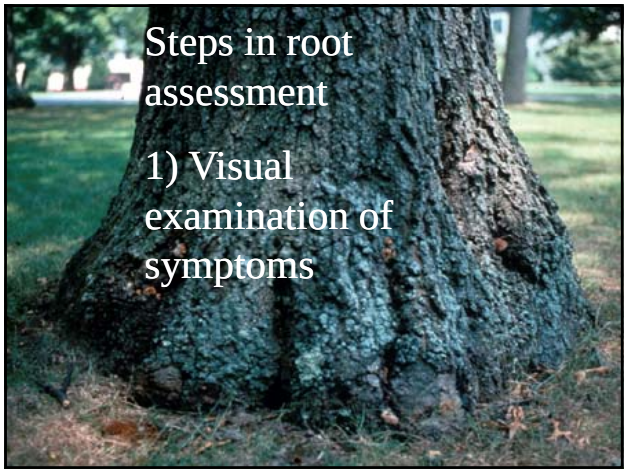
Abstract. This study was developed to determine if commercially available ribbed barriers reduce or increase the stability of trees under severe lateral stress. Green ash (*Fraxinus pennsylvanica*) were planted in November 1996: 6 in surrounding-type tree root barriers and 6 without barriers. Half of each group was pulled over in July 1999 under dry (14% water) soil conditions and the other half was pulled over under saturated (33% water) soil conditions. The force required to pull the trees over was measured as was the wind resistance of the trees. Slightly more force was required to pull over the trees grown within root barriers than the control trees. The force required for the weakest tree, however, was far greater than that exerted by a 100-mph (160-kph) wind. The reason for the increased strength of the root barrier trees appeared to be the deeper root system.

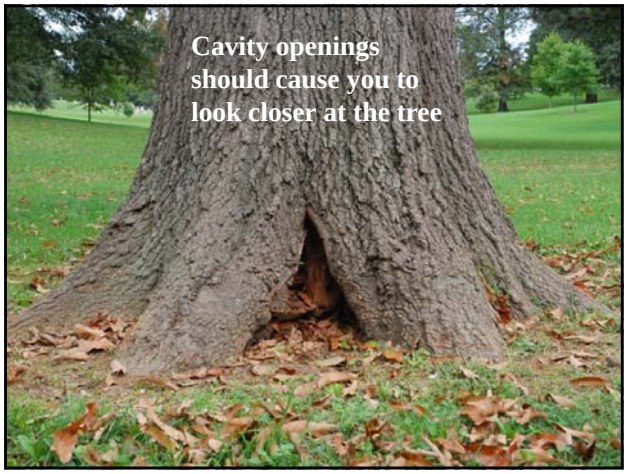
Key Words. Sidewalk damage; root barrier; windthrow; tree failure

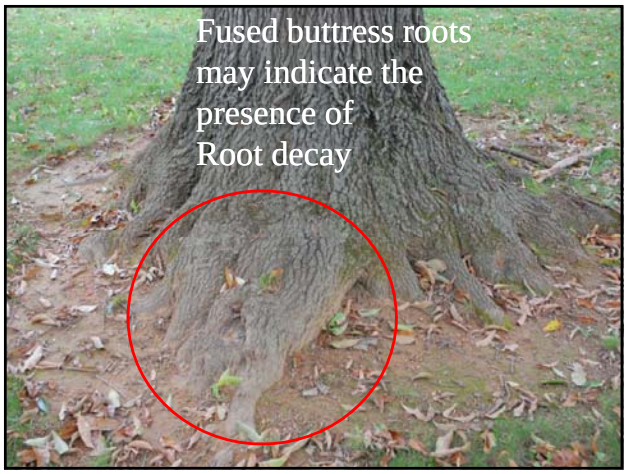
Peper 1998; Wagar 1985). These studies found that surface rooting of trees was significantly reduced close to the installed barrier, with no statistical difference in tree growth. With the exception of Gilman (1995), all studies were conducted with barriers surrounding the root ball, rather than linearly along one side. To gather the data, all studies included root excavation and counting, thereby eliminating the opportunity to test tree stability.

There has been concern that circling root barriers may reduce the stability of trees under extreme wind condition. It has been observed that trees growing near various subgrade structures are more susceptible to windthrow (Francis and Gillespie 1993). This study was developed to determine if commercially available ribbed barriers reduce or increase the stability of trees under severe lateral stress.





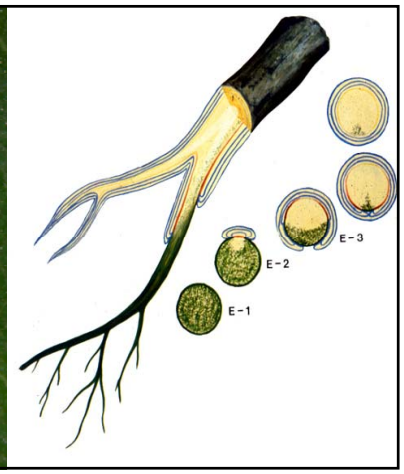




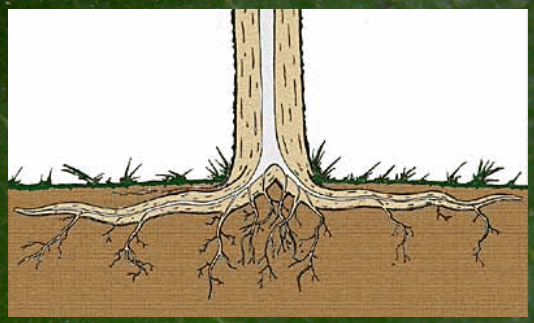
Root Decay

Pattern – From the tips in and from the bottom up

Old trees – Most have some degree of decay



Root Decay Progression



3) Root collar excavation if needed to see the buttress roots

Advanced root decay Assessment

4) Probing for decay

Sounding and drilling for root decay

Advanced Root Decay Assessment

5) Determining thresholds and comparison of your data to know thresholds

How much decay is too much?

Post Hurricane tree analysis to determine tolerable levels of root decay

See: Fraedrich and Smiley. 2002. Tree Structure and Mechanics Conference Proceedings. ISA press.

Root Assessment

Measure DBH

Count all significant buttress roots

Determine depth to decay in each

If less than DBH X 0.15 –Decayed

Determine % of roots with Decay or roots that are severed or missing

Likelihood of Failure

Imminent- > 50% of roots with significant decay, or if decay is uphill or opposite lean

Probable- > 33% of roots with significant decay, or is uphill or opposite lean roots are significantly decayed

Possible- < 33% of roots with Some decay

Improbable - no significant decay or cut roots, not in low or wet site etc

Tree Risk Evaluation, Consider all Factors

Defects

Loads

Adaptive growth

Site factors

Likelihood of Failure

Likelihood of failed part impacting the target

Consequences of the impact