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## Using Remotely Operated Jacks to Fall Dangerous Trees

October 2008

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RS2007-DG03

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# **Using Remotely Operated Jacks to Fall Dangerous Trees**

Final Report RS2007-DG03

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by

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## Findings

- When designing the holding wood so it is sufficiently weak for a 44.5 kN jack to produce the design stress in a straight vertical tree, the results of this paper indicate the total height of the tree is not significant in estimating the width of the holding wood when taking the diameter at the stump height into account.
- When designing the holding wood to maintain the tree in static equilibrium while the falling cuts are being made given naturally occurring destabilizing loads such as an initial lean, the total height of the tree is significant in estimating the width of the holding wood while diameter at stump height is not.
- The true mechanical phenomenon that occurs in the holding wood when a tree commits to falling under self weight is complex. As the backcut side of the holding wood goes into tension fibers can be pulled out of the tree, while on the undercut side cells can be crushed. This paper proposes using a design stress as a surrogate for the true mechanical phenomenon. Existing data suggested compression directed up the tree of 33MPa is a reasonable choice for the design stress, and this was supported by back calculation of the maximum compression in the holding wood from a small sample of test trees.
- It appears for some combinations of dbh and total tree height that a relatively small initial lean could compromise the ability of the holding wood to maintain static equilibrium while the jack is being set. Field testing of the holding wood design process (HWDP) will be conducted to determine if a better balance can be found between resisting naturally occurring destabilizing forces and sufficient weakness so a small jack can initiate displacement.

## **Executive Summary**

This research considers the use of remotely operated light weight hydraulic jacks to remove the faller from the hazardous region near the base of the tree during the critical time when the top of the tree begins to displace. The objective of this procedure is to ensure the tree does not displace when the faller is working at its base, while having a mechanism for initiating displacement of the tree when the faller is in the clear. In this research trees are assumed to be felled in the direction of the lean, which reduces the required jacking force and permits the use of light weight jacks that can be carried as standard equipment.

This research is a preliminary mechanical analysis using the finite element method to consider the performance of small hydraulic jacks combined with novel holding wood patterns in manual tree falling. The objective of the holding wood in this research is to limit displacement of the tree when the faller is working at the base, while permitting a small hydraulic jack to push the tree over without having excessive stump pull or a barber chair. The true mechanical phenomenon that occurs in the holding wood when a tree commits to falling under self weight is complex, as the backcut side goes into tension fibers can be pulled out of the tree while on the undercut side cells can be crushed. This research proposes using a design stress as a surrogate for the true mechanical phenomenon. Existing data suggested compression directed up the tree of 33MPa was a reasonable choice for the design stress, and this was supported by back calculation of the maximum compression in the holding wood from a small sample of test trees.

This research has three objectives. The first objective is to propose a holding wood design procedure (HWDP) for trees where the center of mass is located directly above the center of the stump, with the goal of finding the largest amount of holding wood that still permits a 44.5 kN jack to produce the design stress under static geometric nonlinear analysis. The second objective is to determine the initial angle of lean where self weight alone produces the design stress when applying the HWDP, the goal here is to determine how sensitive the HWDP is to naturally occurring destabilizing loads. The third objective is to determine bounds for the design stress.

The HWDP proposed in this paper had two goals. First, the holding wood must be sufficiently weak so that a 44.5 kN jack can produce the design stress in the holding wood. When considering this design criterion the results of this paper indicate the total height of the tree is not significant in estimating  $HWW$  when taking the diameter at the stump height into account. Second, the holding wood must maintain the tree in static equilibrium while the falling cuts are being made, given naturally occurring destabilizing loads such as an initial lean. When considering this design criterion and designing the holding wood with the HWDP based on the first goal, the total height of the tree is significant in estimating the initial lean that produces the design stress in the holding wood, while  $dst$  is not. The difference between these results is due to the sensitivity of the goal to the horizontal displacement of the center of mass. Since the second goal is considering a leaning tree the horizontal displacement of the center of mass is significant and this is highly correlated with the total tree height.

In this research a successful HWDP holds the tree in static equilibrium while the jack is being set, and allows the jack to initiate falling without excessive stump pull or a

barber chair. It appears for some combinations of dbh and total tree height that a relatively small initial lean could compromise the ability of the HWDP to maintain static equilibrium while the jack is being set. Field testing of the HWDP will be conducted in 2009 to determine if a better balance can be found between resisting naturally occurring destabilizing forces and sufficient weakness so a small jack can initiate displacement.

## 1. RESEARCH PROBLEM/CONTEXT

With the initiation of the faller certification program in British Columbia the number of fatalities in manual tree falling appears to be dropping; however, there are still numerous serious incidents involving certified fallers (BCForestSafe, 2006 and 2007). There are many variables that are difficult for a faller to control and these often result in the faller being struck by trees or debris while working at the base of the tree. On reading the incident summaries corresponding to the accident reports, falling trees and debris striking the faller appear to be the overwhelming hazards to manual tree fallers.

The recommended dimensions of the falling cuts given in this paper are drawn from WCB (1993). When falling a tree a wedge of material is taken out of the side of the tree that is in the intended falling direction. This wedge is termed the undercut, and it is recommended that the horizontal width of the undercut be 25% to 33% of the diameter of the tree (Figure 1). From the side of the tree opposite the undercut, a horizontal cut is brought in towards the undercut in a plane that is 2cm to 5cm higher than the undercut. This horizontal cut is termed the backcut. The backcut is stopped before reaching the horizontal position of the inside of the undercut. The wood between the backcut and the undercut is termed the holding wood, and the width of the holding wood must be sufficient to maintain directional control of the tree. The role of the holding wood is to control the motion of the tree while it is falling; however, at some point in the motion the holding wood must break in order for the tree to fall to the ground.

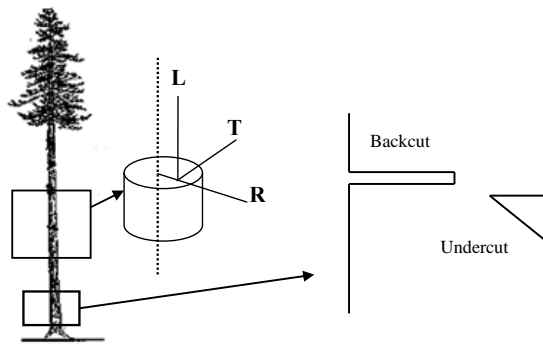


Figure 1, Basis directions and falling cuts

There are the six possible crack alignments in wood;  $TL$ ,  $RL$ ,  $LR$ ,  $TR$ ,  $RT$ , and  $LT$  (Figure 1), where the first letter describes the normal to the plane of the crack and the second letter describes the direction of crack propagation. Barrett (1981) notes the fracture toughness of most species of trees is an order of magnitude higher in the  $LT$  and  $LR$  directions. This is a disadvantage when falling a tree because at some point the holding wood must break in the  $LT$  and  $LR$  systems, and it is preferable to have this happen before a crack propagates in the  $TL$  or  $RL$  systems.

Previous authors (Guimer, 1980, Lindroos et al, 2007) have assumed the holding wood acts like a hinge with the horizontal axis of rotation located in the center of the holding wood. This assumption allows the authors to replace the holding wood with a resultant moment equivalent to the bending resistance of the holding wood. The tree is then assumed to undergo a rigid body rotation about the axis of rotation. Under standard conditions where the holding wood is relatively narrow, these assumptions are useful for predicting resultant loads and rotation rates; however, they do not permit a detailed analysis of the stress field. This is particularly important when considering novel holding

wood patterns, where it is possible for excessive tension to occur in the backcut side of the holding wood. Tension in the holding wood can cause fibers to be pulled out of the base of the tree (stump pull) or cracks to propagate up the tree (barber chair).

This paper will consider the use of remotely operated light weight hydraulic jacks to remove the faller from the hazardous region near the base of the tree during the critical time when the top of the tree begins to displace. The objective of this procedure is to ensure the tree does not displace when the faller is working at its base, while having a mechanism for initiating displacement of the tree when the faller is in the clear. In this paper trees will be felled in the direction of the lean, which will reduce the required jacking force and permit the use of light weight jacks that can be carried as standard equipment.

This paper is a preliminary mechanical analysis using the finite element method to consider the performance of small hydraulic jacks combined with novel holding wood patterns in manual tree falling. The objective of the holding wood in this paper is to limit displacement of the tree when the faller is working at the base, while permitting a small hydraulic jack to push the tree over without having excessive stump pull or a barber chair. In the following objectives design stress refers to a stress value selected to represent the state in the falling process where the tree is committed and will continue to fall due to self weight. The design stress used in this paper will be defined further in Section 3. The objectives of this paper are as follows. The first objective is to propose a holding wood design procedure (HWDP) for trees where the center of mass is located directly above the center of the stump, with the goal of finding the largest amount of holding wood that still permits a 44.5 kN jack to produce the design stress under static

geometric nonlinear analysis. The second objective is to determine the initial angle of lean where self weight alone produces the design stress when applying the HWDP, the goal here is to determine how sensitive the HWDP is to naturally occurring destabilizing loads. The third objective is to determine bounds for the design stress.

## 2. METHODOLOGY

### 2.1 Tree model

This paper considers Douglas-fir (*Pseudotsuga menziesii*). The taper equation developed by Kozak (1988) was used to calculate the inside bark diameter of a tree.

$$\begin{aligned}
 Z &= h_i / H \\
 X &= (1 - \sqrt{(h_i / H)}) / (1 - \sqrt{p}) \\
 d_i &= a_0 D^{a_1} a_2^D X^{b_1} Z^2 + b_2 \ln(Z + 0.001) + b_3 \sqrt{Z} + b_4 e^Z + b_5 (D / H)
 \end{aligned} \tag{1}$$

Here  $H$  is the total height of the tree in meters,  $D$  is the diameter at breast height in centimeters,  $h_i$  is the height up the tree in meters,  $d_i$  is the diameter inside bark at  $h_i$  in centimeters,  $a_j$ ,  $b_j$ , and  $p$  are constants that can be found for various species in Kozak (1988).

Bodig and Jayne (1993) describe a cylindrical section of a tree as being an orthotropic material with cylindrical anisotropy, where the axes of symmetry are the long axis  $L$ , the radial axis  $R$ , and the tangential axis  $T$  (Figure 1). Due to the complex geometry around the falling cuts meshing is simplified if the wood is considered to be transversely isotropic. To consider the wood in the bole of a tree as a transversely isotropic material the elasticity tensor must be made symmetric, and the following must be true.

$$E_T = E_R, G_{RL} = G_{TL}, \nu_{RL} = \nu_{TL} \quad (2)$$

Using the orthotropic material properties for Douglas-fir given by Bodig and Jayne (1993) the elasticity tensor was made symmetric by averaging the coefficients above and below the diagonal in the elasticity tensor, and the elasticity tensor was made transversely isotropic by averaging the coefficients in (2). The engineering constants used in this paper are given in Table 1.

Table 1, Engineering constants for Douglas-fir averaged so it is transversely isotropic

$E_L^a$ (Pa)	$E_T$ (Pa)	$E_R$ (Pa)	$G_{TL}^b$ (Pa)	$G_{RL}$ (Pa)	$G_{TR}$ (Pa)
1.476E+10	8.053E+08	8.053E+08	7.712E+08	7.712E+08	8.508E+07
$\nu_{LR}^c$	$\nu_{LT}$	$\nu_{RT}$	$\nu_{RL}$	$\nu_{TR}$	$\nu_{TL}$
0.362	0.362	0.375	0.020	0.375	0.020

a Young's modulus, b Shear modulus, c Poisons ratio

Adamovich (1979) gives the ratio of total green mass to merchantable volume for Douglas-fir, and this is used in this paper to approximate the mass of the tree including the wood, bark, and crown. The volume of the bole of a tree is concentrated in the lower region of the tree; therefore, using the ratio of total green mass (wood, bark, and branches) to merchantable volume to calculate the total mass of the tree will underestimate the height of the center of mass. Underestimating the height of the center of mass will underestimate the bending moment due to self weight for trees with a significant lean.

The configuration of the falling cuts is presented in Figure 2. In Figure 2  $R$  is the radius of the tree inside bark at the height of the falling cuts,  $DBC$  is the depth of the

backcut,  $HWW$  is the holding wood width,  $DUC$  is the depth of the undercut,  $JN$  is the jack notch depth,  $\delta_i$  for  $i = 1$  to 4 are respectively the thickness of the undercut, distance between the top of the undercut and the bottom of the backcut, the thickness of the backcut, and the thickness of the jack notch, and  $ST$  is the distance from the base of the tree to the bottom of the undercut. Let  $dst$  be the diameter inside bark at  $ST$ , where  $dst$  is equal to the sum of  $DUC$ ,  $HWW$ , and  $DBC$ . Note the undercut is represented as a narrow rectangular section removed from the tree in order to simplify model construction and meshing. Since this paper considers the tree only up to the first few degrees of rotation, representing the undercut as a narrow rectangular section does not create a significant error.

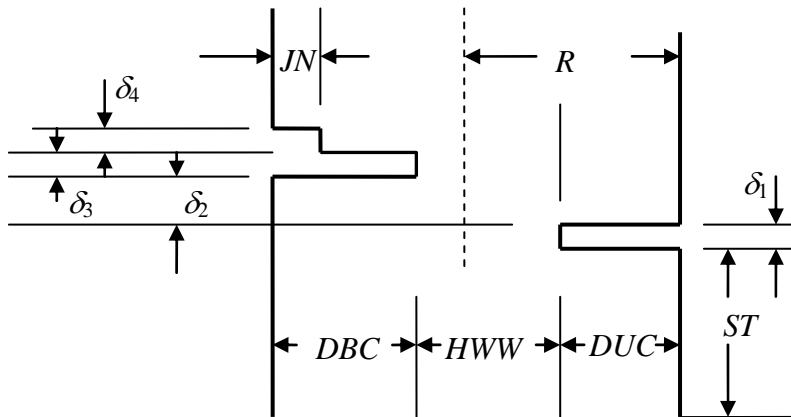


Figure 2, Falling cuts

The bole of the tree was modeled using ANSYS<sup>®</sup> SOLID92 elements. The ANSYS<sup>®</sup> SOLID92 element is a 10 node tetrahedron, with 4 nodes located at the corners and 6 nodes located midpoint between the corners. The Preconditioned Conjugate Gradient

(PCG) solver was used to perform the static analysis, and geometric nonlinearity through large deflections was permitted. For all scenarios considered in this paper displacement of the nodes on the base of the tree was fixed at zero. For scenarios that included a jack force, a force equal to the jack force divided by the number of nodes on the upper surface of the jack notch was applied to each node on the upper surface of the jack notch.

## 2.2 Holding wood design procedure

The goal of this paper is to develop a HWDP that maintains static equilibrium of the tree when the falling cuts are being made, while permitting falling to be initiated by a 44.5 kN jack. Since it is assumed the procedures developed in this paper will not be used for falling a tree against its lean, the limiting condition for the jack to initiate falling is when the initial lean of the tree is zero. In this case the self weight of the tree does not help to overcome the stiffness of the holding wood. This section will develop a HWDP for trees where the center of mass is located directly above the center of the stump, with the objective of finding the largest amount of holding that still permits a 44.5 kN jack to produce the design stress under static geometric nonlinear analysis. In the following section of this paper the ability of the HWDP to support an initial lean of the tree without the jack force will be assessed.

A design stress in the  $L$  direction is used as the design criterion for this section. This is a surrogate for the true physical phenomenon that occurs once a tree is committed to continue falling under its own weight. The true phenomenon is complex and nonlinear as the fibers begin to pull apart under tension on the backcut side of the holding wood, and crush under compression on the undercut side. In this paper the design stress is a

compression value since wood is generally considered weaker in compression than in tension, and there is a concern that high tension values will increase the frequency of barber chairs. There is a wide range between the commonly reported strength values for Douglas-fir, for example Bodig and Jayne (1993) list for unseasoned Douglas-fir the Modulus of Rupture (MOR) as 52MPa and the maximum compression parallel to grain as 25MPa. It is not clear at this time whether the holding wood is better represented as a beam problem where MOR is a useful measure of strength, or as a crushing problem. Data collected by Bennett et al (2004) from full size testing of Douglas-fir log stringers indicated the proportional limit often occurred at 64% of the ultimate load. Thus, the design stress used in this paper will be 33MPa, which is 64% of 52MPa.

WCB (1998) recommends the *DUC* should be between 25% and 33% of *dst*. In this section the *DUC* will be fixed at 30% of *dst*. The scenarios considered in this section are listed in Table 2, where the first 5 columns after the scenario name are the inputs to the model and the last 2 columns report the *DBC* and resulting *HWW* required for a 44.5kN jack to produce the design stress in the holding wood. The first two digits of a scenario name represent the *dbh* in centimeters, the second two digits represent the height in meters, and the last two digits represent the *DUC* as a percent of *dst*.

Table 2; Section 3 scenario specifications.

Name	<i>dbh</i> (cm)	<i>H</i> (m)	<i>dst</i> (m)	<i>DUC</i> (m)	Density <sup>a</sup> (kg/m <sup>3</sup> )	<i>HWW</i> (m)	<i>DBC</i> (m)
402530	40.0	25.0	0.386	0.116	986	0.112	0.159
403030	40.0	30.0	0.391	0.117	986	0.110	0.164
403530	40.0	35.0	0.395	0.119	986	0.107	0.170
404030	40.0	40.0	0.399	0.120	986	0.108	0.172
503030	50.0	30.0	0.484	0.145	848	0.116	0.223
503530	50.0	35.0	0.488	0.147	848	0.117	0.225
504030	50.0	40.0	0.493	0.148	848	0.113	0.232
504530	50.0	45.0	0.497	0.150	848	0.114	0.234
603530	60.0	35.0	0.582	0.175	848	0.128	0.279
604030	60.0	40.0	0.586	0.176	848	0.123	0.287
604530	60.0	45.0	0.591	0.177	848	0.130	0.284
605030	60.0	50.0	0.595	0.179	848	0.131	0.286
704030	70.0	40.0	0.681	0.204	848	0.129	0.347
704530	70.0	45.0	0.685	0.206	848	0.130	0.349
705030	70.0	50.0	0.689	0.207	848	0.131	0.352
705530	70.0	55.0	0.694	0.208	848	0.125	0.361

a Total Green mass to merchantable volume Adamovich (1979)

In Table 2 *dbh* is given since it is an input to the tree taper equation; however, *dst* is what the faller works with. Since *DUC* is fixed at 30% of *dst* in this section the explanatory variables for the HWDP are *H* and *dst*, with the response variable being *HWW*. To test if *H* is significant in estimating *HWW* so that a 44.5kN jack can produce the design stress in the holding wood when taking *dst* into account, consider the following full and reduced models.

$$\begin{aligned}\mu(HWW|dst, H) &= \beta_o + \beta_1dst + \beta_2H \\ \mu(HWW|dst) &= \beta_o + \beta_1dst\end{aligned}\tag{3}$$

Considering the models in (3) *H* was not significant in estimating *HWW* (Extra Sum of Squares F-test, p-value of 0.317). Fitting the second equation of (3) to the data in Table 2 results in

$$HWW = 8.072E - 02 + 7.327E - 02(dst) \quad (r^2 = 0.83) \quad (4)$$

The HWDP developed in this section consists of 1) setting *DUC* to 30% of *dst*, and 2) calculating *HWW* with (4).

### 2.3 Allowable initial lean

The HWDP developed in Section 2.2 considers a tree under the conditions where the ability of a 44.5 kN jack to initiate falling, as defined by achieving the design stress in the holding wood, is the limiting condition. To meet the objectives of this paper it is also important for the holding wood to maintain static equilibrium while the falling cuts are being made subject to naturally occurring destabilizing loads such as self weight acting on an initial lean, asymmetric crown, and wind loads. This section will consider the destabilizing load resulting from self weight and an Initial Lean (*IL*) of the tree. In this section *DUC* is set at 30% of *dst*, and *HWW* is taken from Table 2 for each scenario. This section will use the same model and solution method as used in Section 2.2; however, instead of applying a jack force to the jack notch, *IL* is increased until self weight produces the design stress in the holding wood (Table 3). This gives a measure of the ability of the holding wood to support naturally occurring destabilizing loads.

Table 3, Initial lean that produces the design stress

Name	<i>IL</i> (deg)	Name	<i>IL</i> (deg)	Name	<i>IL</i> (deg)	Name	<i>IL</i> (deg)
402530	5	503030	4	603530	3	704030	2
403030	3	503530	3	604030	2	704530	2
403530	2	504030	2	604530	2	705030	1
404030	2	504530	2	605030	1	705530	1

Again consider the explanatory variables  $H$  and  $dst$ , with the response variable now being  $IL$ . To test if  $dst$  is significant in predicting the  $IL$  required to produce the design stress in the holding wood without the jack force, when taking  $H$  into account, consider the following full and reduced models.

$$\begin{aligned}\mu(IL|dst, H) &= \beta_o + \beta_1 dst + \beta_2 H \\ \mu(IL|H) &= \beta_o + \beta_1 H\end{aligned}\tag{5}$$

Considering the models in (5)  $dst$  was not significant in estimating  $IL$  (Extra Sum of Squares F-test, p-value of 0.329). This is a reasonable result when considering only self weight acting over an initial lean of the tree. The height of the center of mass is more strongly correlated with the height of the tree than it is to  $dst$ , and as the initial lean is increased the resultant vertical load acts on a longer moment arm about the holding wood when the center of mass is higher.

#### 2.4 Field test

The failure mechanism in the holding wood when a tree commits to falling and the magnitude of the design stress that would indicate the point when the tree can no longer maintain static equilibrium is uncertain. Extensive field testing was not possible in this preliminary study; however, there was an opportunity for limited field observations. The objective of the field observations was to collect data that could be used in the finite element model to calculate the maximum compressive stress in the holding wood when the tree was close to committing to falling but still in static equilibrium, and after the faller had completed the backcut. The amount of holding wood left for the static equilibrium point was more than the minimum necessary to maintain static equilibrium

since the faller had to ensure the tree was safe to measure while it was partially cut. In practice fallers continue to cut the backcut as a tree is falling in order to minimize stump pull, which results in the final width of the holding wood being less than that required to ensure the tree will continue to falling under its own weight. Thus, these two data points will bound the design stress.

The faller was asked to stop the back cut before the point where he believed the tree would commit to falling. At this point with the tree in static equilibrium, the depth of the undercut, backcut, and the width of the holding wood were measured. The faller was then instructed to complete the backcut as normal. After the tree was felled the final depth of the backcut and the width of the holding wood were measured. A straight tree with an initial lean is more unbalanced than a tree with the same lean at the base but that sweeps back to the vertical. A straight tree with no initial lean and a straight tree with an initial lean bound the problem of destabilization due to self weight. Thus, trees with noticeable sweep were not used in the analysis since it was not possible to accurately locate points along the stem in this preliminary study. Six Douglas-fir trees were available for analysis after excluding trees with noticeable sweep. Recall the finite element model uses (1) to calculate the diameter inside bark given  $dbh$  and  $H$ , and the  $dst$  calculated with (1) differed slightly from the actual  $dst$  for the test trees. Thus, the  $DUC$ ,  $DBC$ , and  $HWW$  actually measured on the test trees were converted to percents of the actual  $dst$ , and these percents were applied to the  $dst$  calculated by the model to provide the cut depths used in the model. The inputs used for the test trees and the resulting maximum compressive stress in the holding wood, are listed in Table 4.

Table 4, Test tree results

Test Tree	<i>dbh (cm)</i>	<i>H (m)</i>	<i>dst (cm)</i>	<i>DUC (m)</i>	<i>HWW (m)</i>	<i>DBC (m)</i>	<i>IL (deg)</i>	Max Comp (Pa)
Tree3Pre <sup>a</sup>	55.3	37.8	54.0	0.178	0.178	0.184	2	1.5E+07
Tree3Post <sup>b</sup>	55.3	37.8	54.0	0.178	0.065	0.297	2	1.2E+08
Tree4Pre	43.5	35.8	42.9	0.129	0.103	0.197	1	1.3E+07
Tree4Post	43.5	35.8	42.9	0.129	0.039	0.261	1	2.0E+08
Tree5Pre	54.5	38.2	53.3	0.181	0.128	0.224	1	1.3E+07
Tree5Post	54.5	38.2	53.3	0.181	0.048	0.304	1	1.2E+08
Tree6Pre	49.0	36.0	48.0	0.134	0.115	0.230	1	1.2E+07
Tree6Post	49.0	36.0	48.0	0.134	0.043	0.302	1	1.2E+08
Tree7Pre	44.8	36.0	44.1	0.132	0.123	0.185	1	1.1E+07
Tree7Post	44.8	36.0	44.1	0.132	0.044	0.265	1	1.2E+08
Tree11Pre	60.8	38.9	59.3	0.178	0.166	0.249	1	9.9E+06
Tree11Post	60.8	38.9	59.3	0.178	0.059	0.356	1	8.2E+07

a) Pre indicates cut dimensions were measured when the tree was in static equilibrium before committing to falling under self weight.

b) Post indicates cut dimensions measured after the tree had been felled.

Considering the design stress to be bounded by the maximum compression at static equilibrium before a tree commits to falling and after it commits to falling, then the data in Table 4 produces an average upper and lower bound of 125MPa and 12.2MPa. As already noted the upper bound is high for the design stress since fallers usually cut a deeper backcut than is necessary, and the lower bound is low because the faller had to ensure the test trees were safe to measure while being partially cut. Selection of 33MPa for the design stress appears to be a reasonable initial choice since it is at the lower end of the range, and the intent was to produce a tree that would remain in static equilibrium while the jack was setup.

## 2.5 References

- Workers Compensation Board of British Columbia (WCB), 1993, *Fallers' and Buckers' Handbook*, sixth edition, WCB, Vancouver (116p.).
- Barrett J. D., 1981, *Fracture mechanics and the design of wood structures*, Phil. Trans. R. Soc. Lond. A., **299**:217-226.
- BCForestsafe, 2006, *2006 Detailed Serious Injury and Fatality Statistics*, <http://www.bcforestsafe.org/content-nav-stats/nav-stats-5-2006.htm>, accessed July 15, 2008.
- BCForestsafe, 2007, *2007 Detailed Serious Injury and Fatality Statistics*, <http://www.bcforestsafe.org/content-nav-stats/nav-stats-6-2007.htm>, accessed July 15, 2008.
- Guimer D. Y., 1980, *Tree-falling mechanics*, FERIC, Technical Report No. TR-42 (28p.)
- Lindroos Ola, Gullberg Tomas, and Nordfjell Tomas, 2007, *Torques from manual tools for directional tree falling*, International Journal of Forest Engineering, **18**(2):40-51.
- Kozak A., 1988. *A variable-exponent taper equation*. Canadian Journal of Forest Research, **18**(11): 1363-1368.
- Adamovich L.L., 1979, *Engineering characteristics of Canadian trees: Douglas-fir and western hemlock in interior British Columbia*, FERIC, Technical Note No. TN-27 (51p.)
- Bennett, D. M. Modesto, R. Ewart, J. Jokai, R. Parker, S.P. Clark, M.L., 2004, *Bending Strength and Stiffness of Douglas-fir and Western Hemlock Log Bridge Stringers*, FERIC, Advantage Report, **5**(42) (19p.)

Bodig J., Jayne B. A. 1993, *Mechanics of Wood and Wood Composites*, Krieger Publishing Company, Florida (712p.).

### 3. RESEARCH FINDINGS

The HWDP proposed in this paper had two goals. First, the holding wood must be sufficiently weak so that a 44.5 kN jack can produce the design stress in the holding wood. When considering this design criterion the results of this paper indicate the total height of the tree is not significant in estimating *HWW* when taking the diameter at the stump height into account. Second, the holding wood must maintain the tree in static equilibrium while the falling cuts are being made, given naturally occurring destabilizing loads such as an initial lean. When considering this design criterion and designing the holding wood with the HWDP based on the first goal, the total height of the tree is significant in estimating the initial lean that produces the design stress in the holding wood, while *dst* is not. The difference between these results is due to the sensitivity of the goal to the horizontal displacement of the center of mass. Since the second goal is considering a leaning tree the horizontal displacement of the center of mass is significant and this is highly correlated with the total tree height.

The true mechanical phenomenon that occurs in the holding wood when a tree commits to falling under self weight is complex, as the backcut side goes into tension fibers can be pulled out of the tree while on the undercut side cells can be crushed. This paper proposes using a design stress as a surrogate for the true mechanical phenomenon. Existing data suggested compression in the *L* direction of 33MPa was a reasonable choice

for the design stress; this was supported by back calculation of the maximum compression in the holding wood from a small sample of test trees.

#### **4. IMPLICATIONS FOR FUTURE RESEARCH**

In this research a successful HWDP holds the tree in static equilibrium while the jack is being set, and allows the jack to initiate falling without excessive stump pull or a barber chair. It appears for some combinations of dbh and total tree height that a relatively small initial lean could compromise the ability of the HWDP to maintain static equilibrium while the jack is being set. Field testing of the HWDP will be conducted in 2009 to determine if a better balance can be found between resisting naturally occurring destabilizing forces and sufficient weakness so a small jack can initiate displacement.

#### **5. POLICY AND PREVENTION**

##### **5.1 Identification of policy and prevention implications arising from the research**

The goal of this research is to remove manual tree fallers from the base of the tree during the dangerous phase when the tree first begins to move. The results of this research indicate small remotely operated hydraulic jacks are a possible method of initiating tree displacement; however, field testing is required to understand how the complicated mechanics of the holding wood will affect the reliability of this method. Field testing will begin in June 2009.

##### **5.2 Relevant user groups for the research results**

Relevant user groups include professional manual tree fallers and forest managers responsible for manual tree fallers.

### 5.3 Dissemination/Knowledge Transfer

The extension activities undertaken as part of this project include;

- 1) Poster presentation at the Malcolm Knapp Research Forest, 30 in attendance including the president of UBC and senior staff (September 22, 2008).
- 2) Submission of journal article to the International Journal of Forest Research (To be submitted October 15, 2008)
- 3) Submission of a Link article to FORREX (Submitted September 30, 2008)