WOOD HARVESTING

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ANALYSIS OF LINE TENSIONS AND BACKSPAR STRESSES IN A SKYLINE SYSTEM: A PILOT STUDY

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Abstract

This report summarizes a pilot study that investigated how loads that are applied to skyline systems in second-growth thinning operations affect the line tensions and stress distribution in the backspar. The maximum tension in the skyline occurred when the turn was fully suspended under the carriage. In the backspar that was examined, compression was the critical stress. By recognizing how the critical loads produce stresses on backspars, procedures can be developed that will limit these stresses.

Introduction

Many of the second-growth stands targeted for commercial thinning on the British Columbia coast are on sites that were originally harvested with skyline systems. The original road systems, if restored, are best suited to similar rigging systems for the second entry. Current cable systems for commercial thinning are usually smaller than those used for the initial harvest, and require adequate clearance to limit soil disturbance and damage to the residual stems. To achieve adequate clearance, it is often necessary to use backspars and intermediate supports. There are, however, concerns that backspars rigged in immature stands will not support the required loads.

Forest engineering software may be used to determine deflection requirements for cable systems and to estimate cable forces along the skyline. However, there is no simple procedure or computer utility to determine the strength requirements for the spar system.

Other studies have examined the structural characteristics and critical loads of spar trees. Structural analysis of spar trees was suggested by Sessions et al. (1985) to be a problem involving a flexible column and a partially rigid base. Pyles (1987) found that base stiffness could be "expressed as a power function of tree diameter at a standard height." Using this information, one can determine the maximum stress in the spar tree, for a given load applied by the standing rigging.

Carson et al. (1982) and Young (1993) suggested methods for determining guyline tensions in spar trees. Both Carson et al. and Young treated the spar tree as a rigid pinned column, where the stiffness of the base did not contribute to the stiffness of the structure. Kendrick and Sessions (1991) proposed a method for calculating a standing skyline's load path. Alternatively, this solution can be used to determine the tension in the skyline for a given clearance.

This Technical Note describes work done for a B.S.F. graduating thesis (Lyons 1997) to quantify the forces applied to second-growth backspars used in cable commercial thinning, and to develop a simple method for analyzing their structural characteristics. The work done with the thinning operation served as a pilot study to test the methods of data collection and analysis. The Forest Engineering Research Institute of Canada (FERIC) recognized the value of this work for its members and assisted the author with advice and the loan of data collection equipment.

Keywords: Cable logging, Skyline, Backspars, Guylines, Intermediate support, Stress distribution, Commercial thinning, Coastal British Columbia.

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Objectives

Accurately determining the load-carrying capacity of a backspar is a complicated task. It requires a three-dimensional solution to the forces acting through the skyline, skyline tailhold, tree block and strap, and guylines. It is also necessary to obtain the displacement of the backspar caused by loading.

The objectives of this study were to:

- Quantify the forces applied to the backspars.
- Determine whether shear or normal stress limits the capacity of backspars.
- Identify the magnitude of the dynamic forces applied to the backspars during inhaul.

System Description

This study was conducted on a commercial thinning operation using a Washington 78SL swing yarder with a Maki Mini-Mak II motorized carriage (Figure 1). The yarder was set up in the shotgun configuration with the mainline on the front drum and the skyline on the middle drum. The breaking strength of the skyline (22-mm diameter, swaged) and the mainline (19-mm diameter, swaged) were 428 and 307 kN, respectively. The chokers used (16-mm diameter, regular line) had a breaking strength of 157 kN.

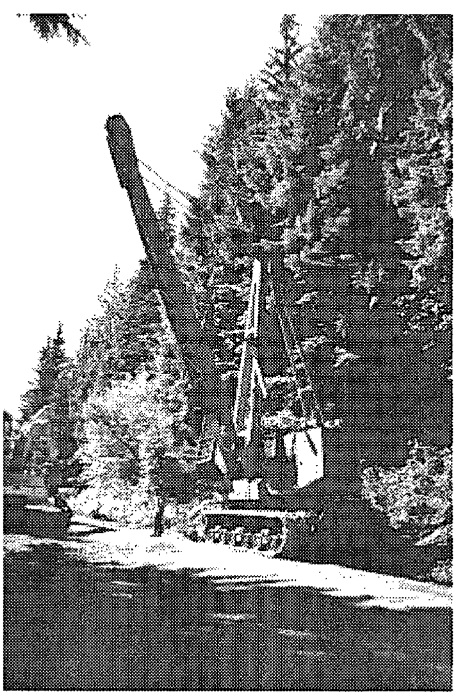

Figure 1. Washington 78SL swing yarder.

The Mini-Mak II carriage is a clamping-type carriage, which was locked in place adjacent to the turns to be yarded. The internal motor powered a capstan which fed slack from the mainline, and then the chokersetters pulled the mainline laterally to hook preset chokers. With the carriage clamped, the operator was then signalled to draw the turn laterally towards the skyline corridor. Once the turn was suspended under the carriage, the clamp was released and the carriage was yarded to the landing.

Each backspar was rigged with four guylines (Figure 2). The rigging height varied between 12 and 22 m, depending on the clearance requirements and available support trees. The diameter at breast height (dbh) of the backspars ranged from 45 to 70 cm, with total tree heights up to 45 m. The guylines were attached to the backspar between 0.5 and 1.5 m above the tree strap rigging point.

The intermediate supports were rigged with two guylines. As with the backspars, these guylines were also attached between 0.5 and 1.5 m above the tree strap rigging point (Figure 3). To support the skyline jack, a tree block was hung on the tree strap. The snake (i.e., the line that supports the skyline jack) was run through the tree block and then to a tailhold perpendicular to the yarding corridor. When the snake was tensioned, the skyline jack was raised into position and pulled away from the intermediate support to provide yarding clearance.

Study Methods

Data Collection

An untopped western hemlock with a dbh of 62 cm and height of 41 m was used as the backspar for both the static and dynamic analyses.

Static Stress Analysis. The following procedure was used to collect the data for the static analysis (Figure 2).

1. A transit and nylon chain were used to locate the cable anchor points and backspar base relative to an established benchmark. In addition, the tree block rigging point, guyline rigging point, and treetop were located on the backspar for the loaded conditions. A point on the skyline 12 m towards the yarder from the tree block was also established as a reference for geometric calculations.
2. Load cells were inserted into the three load-carrying guylines and the skyline (Figures 4 and 5). A fourth guyline, located in front of the backspar, was not instrumented as it became redundant when the skyline was tensioned.

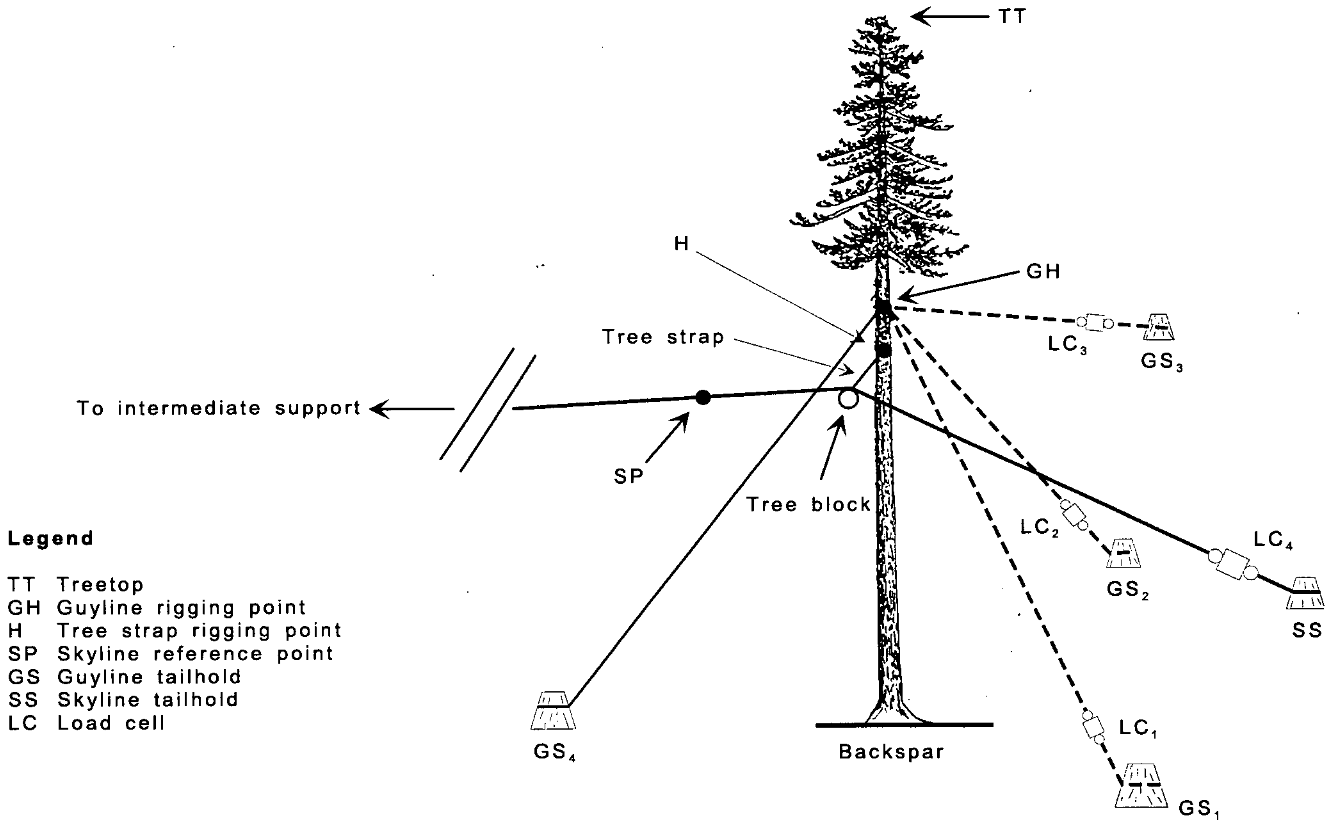

Figure 2. Rigging configuration for backspar system.

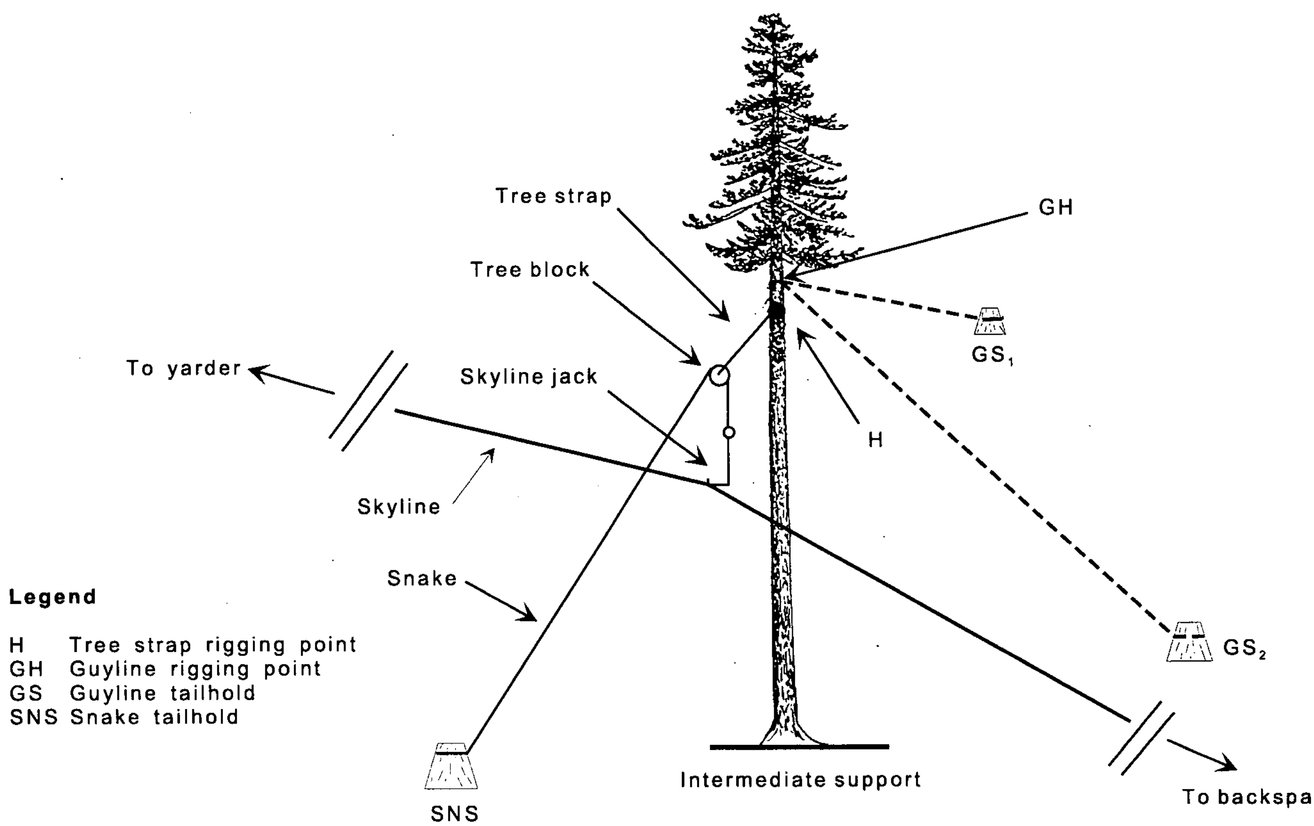

Figure 3. Rigging configuration for intermediate support system.

Figure 4. Load cell installation on guyline.

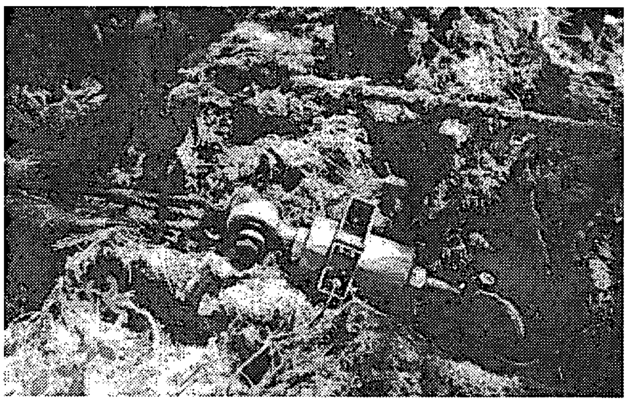

Figure 5. Load cell installation on skyline.

3. The skyline was brought up to its operating tension, and the tensions in the standing rigging were measured. A datalogger was used to receive the load cell outputs, and a laptop computer was used to view the tensions that resulted.

Dynamic Analysis. During the dynamic analysis, skyline and guyline tensions were recorded during both lateral yarding to the skyline corridor and carriage inhaul to the landing. The data logging system used was capable of reading only one load cell at a time; therefore, the tension in only the skyline or one guyline could be measured during dynamic testing.

The following procedure was used for the dynamic tests:

1. The datalogger was connected to the load cell of interest (skyline or guyline).

2. The tension was recorded at the following points during the inhaul cycle:

   - When the turn broke free.

   - During lateral yarding.

   - When the turn was fully suspended under the carriage.

   - When the carriage passed over the intermediate tree jack.

   - As the carriage travelled between the intermediate support and the yarder.

Data Analysis

A static analysis was conducted to examine the relationship between the tensions in the skyline and guylines, and to calculate the stress distribution in the backspar. The backspar was divided into 30 sections in order to calculate the internal loads and stresses. Ten sections of equal length were established in three segments:

- The base of the tree to the tree strap rigging point.

- The tree strap rigging point to the guyline rigging point.

- The guyline rigging point to the treetop.

Three inputs were needed to calculate the stress distribution in the backspar:

- Line tensions and force directions: line tensions were measured directly using the load cells, while the force directions were solved using geometry.

- Backspar base reactions: Since the final position of the backspar and the tensions and angles of the cables were known, the backspar base reactions were solved as statically determinate situations. These reactions were used to determine the shear and bending stresses in the column.

- Bole and crown mass distributions: The masses of the bole and crown cause both axial and bending stresses in the backspar. The mass of the bole was calculated by first determining the volume of each of the 30 sections, using cross-sectional areas (inside bark) calculated with a taper equation (Kozak 1988). Then, the total volume was multiplied by the density of the wood.

  The mass of the crown was more difficult to estimate. An equation for crown mass (Kurz 1989) was examined to determine the importance of crown mass in this analysis. It was found that when the crown was pruned to a height above the guyline rigging point, the increase in normal stress on the internal cross-sections was less than 1%. Therefore, the forces due to crown were not included in this analysis.

Below the guyline rigging point, the centroids of each of the two bole segments were set at one-half each segment height. Above the guyline rigging point, the centroids of the bole segments were set at two-fifths the segment height (due to increased taper in the treetop segment).

The above inputs were used to calculate the internal axial forces, shear forces, and bending moments for the top of each section face.[1] The total normal stress was calculated through superposition of the stresses caused by the axial component of the vertical forces, axial component of the horizontal forces, and internal bending moment.[2] The maximum shear stress (on an element at the centre of each cross-section) was calculated by superposition of the shear stresses caused by the transverse components of the vertical and horizontal forces.[3]

Results and Discussion

Static Stress Analysis

The static stress analysis performed only approximates the internal stresses in the backspar, since eccentricity due to loading is not considered. The internal normal and shear stress distributions are presented graphically in Figures 6 and 7, respectively. The positions of the tree block, rigging points, and anchors (guyline and skyline tailholds) (Figure 2), combined with the skyline tension, will determine the spar tree loading.

The normal stress distribution along the backspar is presented as the maximum tension and compression acting on each cross-section (Figure 6). The tension and compression curves are almost mirror images, as the main load is due to the internal bending moment. However, the negative compression curve has a slightly higher magnitude than the positive tension curve. This is due to the negative curve being affected by negative forces—the compression from bending, tree weight, and the axial cable load, whereas the positive curve is a result of positive tension from bending as well as the negative influence of compression from the cables and tree weight.

The shape of the normal stress curves is a function of the change in the cross-sectional area and the applied loads. The maximum normal stress is shown at about 7 m above the base of the tree. However, this would likely change in two ways if buckling was included in the analysis. Firstly, this maximum would shift upwards to about 15 m, as this is the region where most of the observed failures occurred. Secondly, the magnitude of the maximum normal stress would increase, as the added eccentricity would increase the internal bending moment.

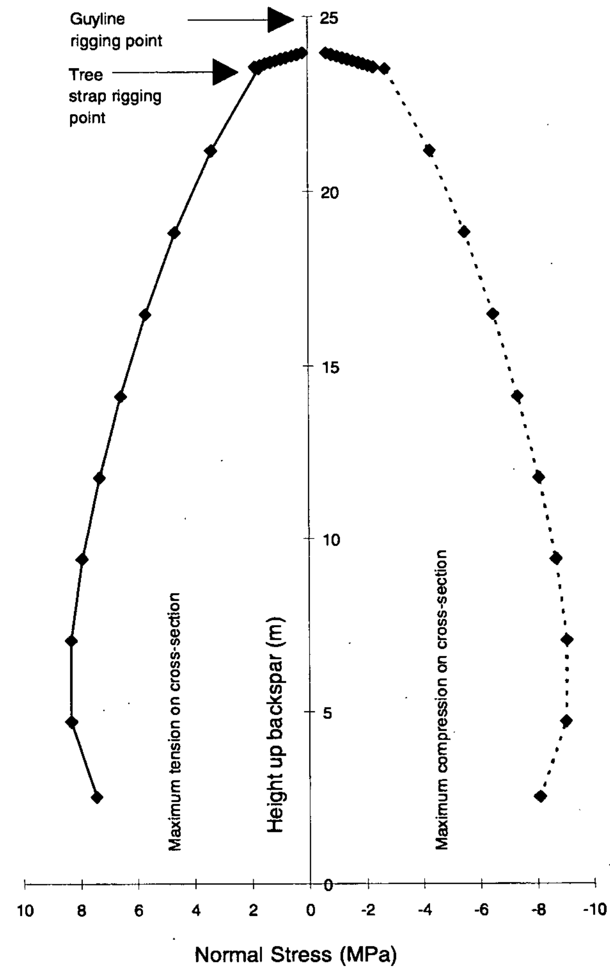

Figure 6. Maximum normal stress distribution up the backspar.

In the shear stress distribution diagram, the shear stress curve is non-linear below the tree strap rigging point (Figure 7). The shape of the curve is the result of the combined effects of the shear force acting on the centroid and area of each cross-section.

There is a spike in the shear stress curve where the tree strap force is applied. The shear stress drops to near-zero as the guyline forces are applied. Though the shear stresses shown are low, the effect of local stress concentrations must be considered. The method of analysis assumes that the points of interest are sufficiently distant from the points of application, and are therefore unaffected by local stress concentrations.

1 Axial force: sum of the forces acting perpendicular to the cross-section surface. Shear force: sum of the forces acting parallel to the cross-section surface. Bending moment: amount of torque applied to the cross-section and required to hold the segment below in equilibrium.

2 Normal stress: axial force divided by the cross-sectional area (in MPa or psi).

3 Average shear stress: shear force divided by the cross-sectional area (in MPa or psi). For a definition of maximum shear stress refer to Hibbeler (1994), pp. 374 and 460.

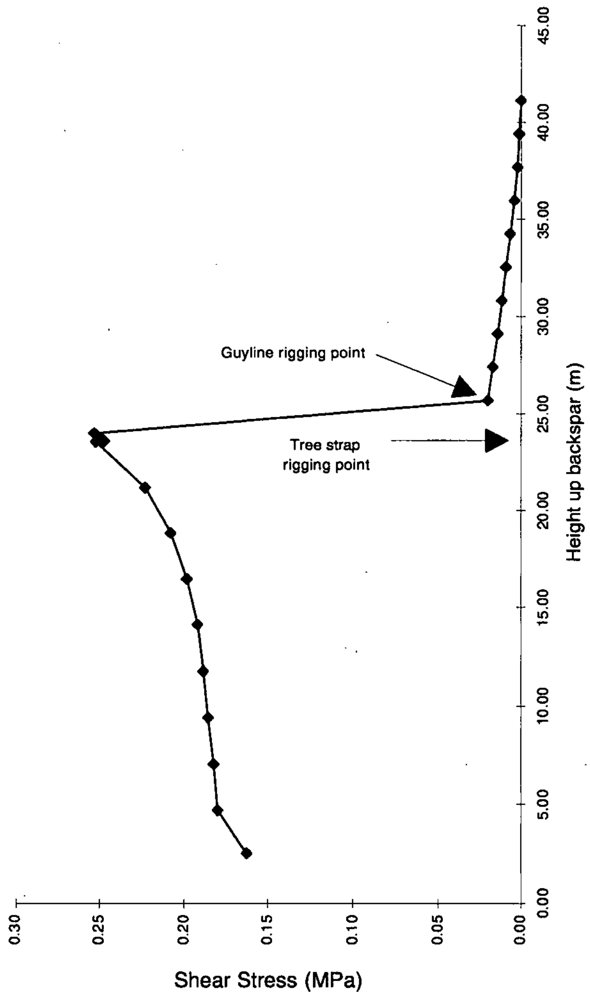

Figure 7. Maximum shear stress at the centre of the cross-section.

Line Tensions During Dynamic Testing

Table 1 summarizes the skyline tension observations made during yarding. During carriage inhaul, the highest skyline tensions occurred when the load was suspended under the carriage, with the exception of hung-up turns. When the turn was suspended under the carriage, the full weight was supported by the skyline. During lateral yarding, there was sufficient lift to partially suspend the turn, and only a portion of the turn weight was supported by the skyline.

The skyline tensions were relatively constant while the carriage was yarded to the landing, although a noticeable drop in tension occurred when the carriage passed over the intermediate support jack. When the carriage passed over the jack, the weight of the carriage and the turn were supported by the snake, and the skyline tension dropped to about the same tension as when the carriage was empty. This could be important when rigging intermediate supports with this configuration. When the snake is used to both support and laterally displace the jack, a block purchase results. This will increase the load in the strap supporting the tree block, and thus the intermediate support. If large loads are expected occasionally, it may be advisable to lower the turn so that it is only partially suspended as the carriage passes over the jack.

Table 2 summarizes the guyline tension observations made during yarding. The guyline observations were made on the most critical guyline for each case. The maximum line tensions occurred during aborted loads and when a stump was choked. Hang-ups occurred more frequently during longer lateral yarding distances.

In this study, the maximum line tensions were determined by stalling the torque converter with the transmission in third gear and the engine operating at 1 800 rpm. This technique provides maximum loads that are within the working load limits for this skyline (breaking strength is 139 kN and the safe working load is 428 kN). If this system is to be used in downhill yarding, the highest tensions would be at the skyline tailhold instead of at the machine, and overloading the skyline could become a problem.

Conclusions

Static Stress Analysis

The internal bending moment in the backspar dominates the normal stress distribution. The method of analysis used in this study only partially recognizes this effect. To accurately predict the internal bending moment,

Table 1. Average Skyline Dynamic Tension Observations

		Skyline Tension (kN)					
Turn size	Number of samples	Empty carriage	At breakout	During lateral yarding	When turn susp. under carriage	When carriage over int. support	When carriage b/w int. support and yarder
Small	5	88.2	--	100.8	109.0	93.4	102.3
Medium	3	92.3	--	109.0	120.0	95.6	111.2
Large	2	88.7	146.8	129.0	140.1	102.3	115.6
Choked stump	1	106.8	154.8	--	--	--	--

Table 2. Average Guyline Dynamic Tension Observations

Turn size	Number of samples	Guyline Tension (kN) Empty carriage	At breakout	During lateral yarding	When turn susp. under carriage	When carriage over int. support	When carriage b/w int. support and yarder
Small	1	12.5	21.4	17.3	17.3	12.0	13.3
Medium	1	12.6	--	24.0 [a]	15.1	--	14.2
Large	1	12.5	--	19.6	23.1	--	20.0
Large aborted	1	12.5	37.4	--	--	--	--

[a] The higher guyline tension during lateral yarding was due to hang-ups caused by longer lateral yarding distances.

the eccentricity due to bending must be included. However, this is difficult as many of the factors involved are highly variable or cannot be measured directly.

The maximum shear stress in the backspar occurs between the rigging points of the tree strap and guylines. The magnitude of the shear stress is not affected by the distance separating these two points, but by the skyline tension and the geometry of the standing rigging. Poorly located tailholds will increase the tensions required to maintain equilibrium in the system, and thus increase the shear stress.

Line Tensions

Lift is important to limit skyline tensions during lateral yarding, and to allow the turn to swing into lead on the yarding corridor without damaging the residual stems. If it is not possible to raise the leading end of the turn, impacts with fixed objects such as stumps will drive the line tensions above the acceptable limits. With adequate clearance, the greatest skyline tensions occur when the turn is fully suspended beneath the carriage.

When the carriage passes over the jack at the intermediate support, the weights of the carriage, turn, and skyline are upheld by the intermediate support. If the intermediate support is limiting the system, lowering the turn so that it is partially suspended while passing the skyline jack may be advisable.

Recommendations

Good rigging and logging practices will help avoid situations where failure of the backspar could occur. The effective location of tailholds will decrease the tensions required to support a given load. Maintaining adequate clearance will reduce the magnitude of the maximum tensions. Because the skyline tension increases dramatically when hang-ups occur, it is important to locate yarding corridors close enough to avoid hang-ups. This is increasingly important as the size of the backspars decreases.

To determine the critical line tensions with respect to the failure of backspars, further study is required. Because the reactions at the base of the backspar cannot be measured directly, and due to the variability in the strength of standing timber, destructive studies may be the simplest way to quantify the diameter–strength relationships. Destructive testing should be done over a range of backspar diameters and species so that statistically significant strength relationships can be determined. The desired outcome of a destructive study would be a set of simple tables, graphs, or equations. These could be used by logging practitioners to determine tension limits in the tree strap based on specific tree sizes and species, and on rigging configurations.

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