EVALUATION OF CURRENT RIGGING TECHNIQUES USED TO DISMANTLE TREES

By Andreas Detter

This article presents the findings of a research project carried out by Brudi & Partner TreeConsult and Treevolution Arboricultural Services, Chris Cowell (Treepartner), and Paul Howard (ArBO).

Ropes and rigging have been used to dismantle trees for a long time. In recent years, traditional rigging techniques have been replaced by more advanced methods that involve new equipment and rope constructions that offer advantages but that still bear a variety of risks.

In 2006 and 2007, a study into rigging operations was funded by the British Health and Safety Executive and Forestry Commission and carried out in a research study conducted by arborists, trainers, and consultants in Great Britain and Germany. The project set out to determine best practices in carrying out risk assessments prior to dismantling a tree, planning and organizing rigging operations, and selecting measures to mitigate risks and prevent accidents. The final report will be published early in 2008 and will be available online soon at www.hse.gov.uk.

Rigging is one strategy for dismantling trees. It combines synthetic ropes, blocks, and the tree in a dynamic structure that is designed to be loaded with falling logs, often of considerable mass. The different components interact with each other in ways that are complex and not fully understood. Rigging may expose climbers and their equipment, as well as the tree, to loads that are great in magnitude and hard to predict. Hazards involved in rigging are significantly greater than in most other arboriculture operations, and so are the risks for climbers carrying out such operations.

The late Peter Donzelli began to study forces generated from rigging operations as early as 1998. Video footage shot during his project was provided by ArborMaster Training and evaluated by Brudi & Partner TreeConsult in 2004. The results indicated significant differences between the log's flight path (trajectory) and the mechanical model behind current force estimations.

Therefore, a pilot study was carried out by TreeConsult in cooperation with ArBO, a tree company in Germany, to study a rigging operation in greater detail: specifically, snatching logs off a vertical stem with the lowering device locked, not letting the sections run ("snubbed off" rigging scenario). This scenario was considered to represent a worst case; it could accidentally occur when letting logs run and will eventually generate great peak forces.

Real rigging operations were performed in a sports science laboratory and studied using a digital tracking system and high-resolution sensors. Additional field tests were carried out and jointly evaluated with data that Peter Donzelli had gathered when he worked on a project funded by the TREE Fund in 1998 which, due to his untimely death, was not completed.

Throughout this process, the objective was to investigate four basic issues with regard to the "snubbed off" rigging scenario:

- **Kinematics:** What are the movements of the log, rigging system, and stem when the log breaks off from the hinge and subsequently falls into the rope?
- **Energy dissipation:** How is this energy dissipated in the rigging system? By what means and to what degree do the different components absorb the energy?
- **Safety margins:** What are the peak forces that components of a rigging system must bear? How great are the actual safety margins in a worst-case scenario?
- **Dynamics:** What are the reactions of the remaining tree in a worst-case rigging scenario? What are the effects of loads and motions generated by rigging operations on a climber's body?

Kinematics of Logs in a "Snubbed Off" Rigging Scenario

Kinematics is the study and description of how things move. Because the sequence of movements involved in rigging operations was not fully understood, the motion capture technique was used to study a number of operations:

> *Motion tracking, or motion capture, started as a photogrammetric analysis tool in biomechanics research in the 1970s and 1980s and expanded into education, training, sports, and, recently,* computer animation *for* cinema *and* video games *as the technology matured. A performer wears markers near each joint to identify the motion by the positions or angles between the markers . . . . The motion-capture computer software records the* positions, angles, velocities, accelerations, *and* impulses, *providing an accurate digital representation of the motion.* (www.wikipedia.org)

A stem 5.5 meters (19 feet) long, which was 35 centimeters (14 inches) in diameter at the base, was cut fresh from a Norway spruce (*Picea abies*) and fixed in a vertical position. Four logs 1.5 meters (5 feet) long, roughly 30 centimeters (1 foot) in diameter and weighing between 55 and 65 kilograms (120 to 140 pounds) were snatched.

After each drop, the top of the stem was cut at 3.5 meters (11.5 feet) and replaced by a 2-meter-long (6.5-foot) section cut fresh from a similar spruce tree. The new part was bolted to the remaining stem using steel binders. Then, a new anchor point was set up using the same eye-sling. The notch and back cut were set at 4 meters (13 feet) above ground in undisturbed wood.

Markers were placed on the stem and the log, which could be automatically traced in video footage by specialized software. A commonly used rigging system was set up, consisting of a Port-a-Wrap friction device at the base of the trunk and an arborist block installed at a height just below 4 meters (13 feet). A 14-millimeter (9/16-inch) double-braid rope was run through the block and attached to the log, using a half-hitch with a timber hitch. In this rigging setup, the rope was tensioned by hand, wrapped around the friction device, and tied off.

The climber was equipped with markers at the position of joints and on the head in order to enable the motion capture software to create a "matchstick man." To monitor the stem's reaction during the dismantling operation more precisely, high-resolution strain gauges were placed on the stem. When under load, the stem would bend, causing its marginal fibers to be stretched or be compressed, respectively, on opposite sides. Strain gauges are able to record fiber elongation at an accuracy of 1/1000 millimeter. Such gauges are also used in pulling tests to evaluate structural defects in living trees, such as the Elasto-Inclinomethod or Statics Integrated Method (Sinn and Wessolly 1989; Brudi 2002).

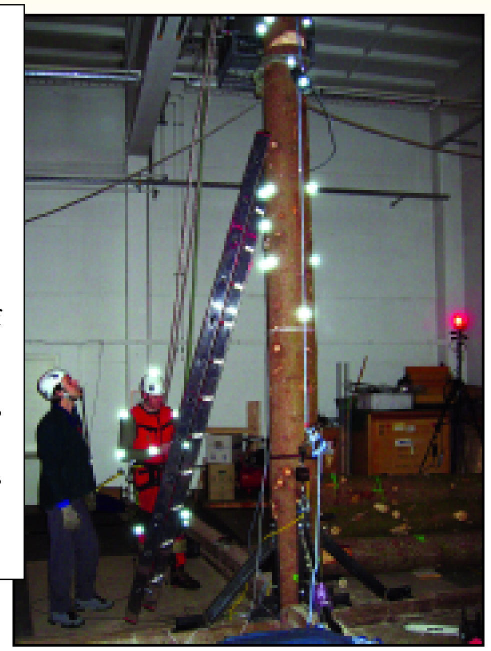

Figure 1. ***Stem and rigging set-up.*** **Markers placed on the tree and the rigging system to track different motions (from top to bottom): the flight curve of the log, displacement and eventual slippage at the rigging point, deflection of the trunk, stretch in the rigging line.**

In the background, the red LED light at one of the eight high-speed cameras used to record the kinematics is visible.

Figure 2. ***Tracking the motion of the climber.*** **Two strain gauges (Elastometers; red arrows) measure stretch in marginal fibers if the stem bends under load (pulling it to the right in this picture).**

The base of the stem was fixed to wooden beams with a framework of steel binders. The top of the trunk was able to move freely, and its flexibility was measured in pull tests prior to the drop tests.

A WORST-CASE RIGGING SCENARIO

Four drop tests were recorded—two using a conventional notch (the bottom cut running horizontally) and two with a Humboldt notch (the bottom cut inclined downward), both with a 45-degree mouth. Position and depth of the back cut were kept constant, in order to produce comparable hinges. The positions of all markers and of the log's center of gravity were tracked throughout the entire dropping sequence. They could be displayed by specialized software in 3D, after processing and filtering the raw data.

The four drop tests revealed a distinct flight curve that was similar for all logs in this test series. The log's center of gravity followed a trajectory that was generated from

- increasing lean, as the log pivots over the hinge;
- forward thrust and rotation generated as the log jumps off the notch;
- acceleration due to gravity; and
- the force of the rigging line pulling on the log.

The centroid flight path can be broken down into five successive phases, which were partially described in *The Art and Science of Practical Rigging* (Donzelli and Lilly 2001):

1. As the climber pushes the log or a ground worker pulls on the tagline, the log pivots over the hinge, while the fibers in the hinge bend and the notch gradually closes. On slender stems, stem deflection may occur as the weight of the leaning log pushes back against the hinge.
2. After the hinge is broken, and the notch is fully closed, the log jumps away from the stem and starts an increasingly vertical fall (similar to the "ballistic curve" of a falling throwbag).

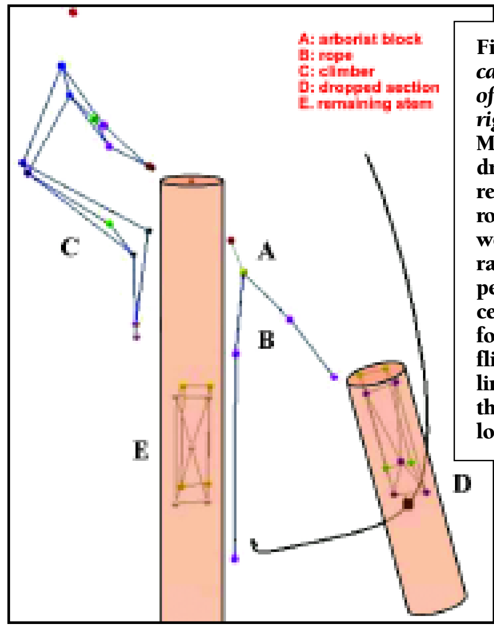

Figure 3. ***Motion-capture recording of a "snubbed off" rigging scenario.*** **Motions of the dropped section, the remaining stem, the rope, and the climber were recorded at a rate of 240 pictures per second. The log's center of gravity followed a distinct flight path (black line that crosses through the dropped log section).**

3. As the log is being stopped by the rope, the flight path's direction is diverted back toward the stem. At the same time, the stem is being pulled forward, and the block slides down the trunk until the anchor sling grips tightly. The distance of fall is increased by the tightening of knots, cordage extension, and slippage (occurs as a length of rope is pulled through the supplementary hitch at the log—often a half-hitch—and out of the wraps on the locked friction device).
4. The peak force in the rope occurs at the instant illustrated in Figure 3, when rope stretch and deceleration of the log both are at maximum. Peak deceleration (a rapid change in speed) generates a peak force—the same force that pushes you forward if you slam on a car's brakes.
5. After the peak force occurs, the stem sways backward while the log swings toward the stem and finally hits it. Amplifying oscillations may occur that compromise the climber's safety, followed by a period of settling down.

Only slight differences were observed between logs' flight curves for the two types of notches. When the Humboldt notch was used, the horizontal displacement of the log was slightly greater than with a conventional notch.

These observations also match the results of close-up video recordings of two breaking hinges, which were recorded at 2,500 pictures per second. One log, 1.5 meters (5 feet) long was cut off the undisturbed stem using a 45-degree conventional notch; a second log of the same length was cut using a 45-degree Humboldt notch. Both sections were pulled off using a tagline and dropped without a rigging system ("free-falled"). The breaking hinge was filmed in a small section of the stem. The log and the remaining stem were each equipped with two round markers with black-and-white sections to enable tracking their movements (Figure 5).

In this example, the conventional notch seemed to generate less forward thrust, and the log rotated more quickly. When using a Humboldt notch, the log jumped off in a horizontal direction at greater speed after separating from the hinge (red arrows in Figure 5). While some arborists confirm this result, others have reported the opposite. The kinematic observations may have been affected to some extent by specific wood fiber properties in spruce trees and may not be suitable to derive a general rule. Therefore, further tests would be required to verify the findings in the future.

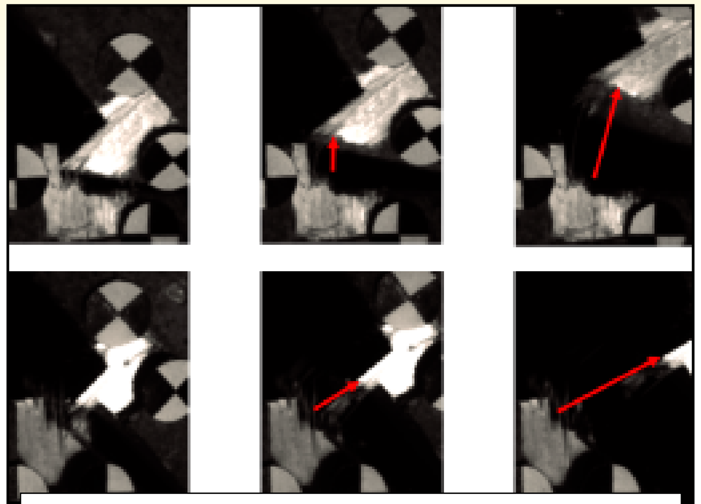

Figure 5. Conventional (top) and Humboldt notch (bottom) 36, 72, and 120 milliseconds after the hinge is fully severed (red arrows point along former fiber connections)

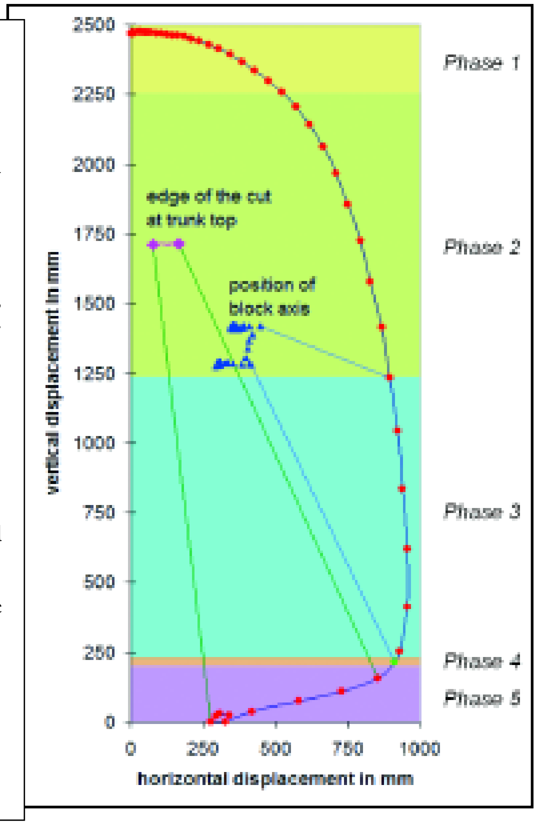

Figure 4. *Example of kinematics in a "snubbed-off" rigging scenario.* The red dots indicate the position of the log's center of gravity at 42-millisecond (0.042-second) intervals, which is a common shutter rate of standard film (24 pictures per second).

While the log slowly pivots over the hinge, the notch closes until the log breaks free. During freefall, speed increases (indicated by larger distances between two subsequent red dots).

As soon as the rope takes up load, it diverts the direction of the log's fall. At the same time, the block is being pulled down (blue lines) while the trunk bends under the load (pink rhombus indicating the position of the cut).

After the peak force occurs (indicated by the bright green dot), the stem sways back as the tension in the line is partially released (green lines).

Similar trajectories for logs were plotted from later field tests, even though a 70-degree, open-face notch was used then. Twenty-three sections of varying dimensions were snubbed off, yet the motions tracked in video footage remained similar. Considerable differences occurred when branches and leaves were left on the falling section. This appeared to be a result of the greater aerodynamic drag on the upper parts of such sections, which reduced the speed of rotation. It caused the section to glide downward in a more or less horizontal position before it rotated more quickly when the rope tension increased to peak load, unlike the logs that quickly tipped over after jumping off from the notch.

In field tests, forces reached their maximum when the two legs of the lowering line formed angles between 32 and 42 degrees at the block. Because, at that instant, the lead of the rope is not running parallel to its fall, the line force is not doubled at the anchor point. If peak forces in lead and fall act on the block at a mean angle of 37 degrees and if friction in the block is taken into account (friction effort was assumed to be at least 10 percent), line forces will generate a reaction force at the block that is roughly 1.8 times the force in the lead (instead of twice the line force). This reaction force acts on the anchor point at an angle of roughly 20 degrees (Figure 6).

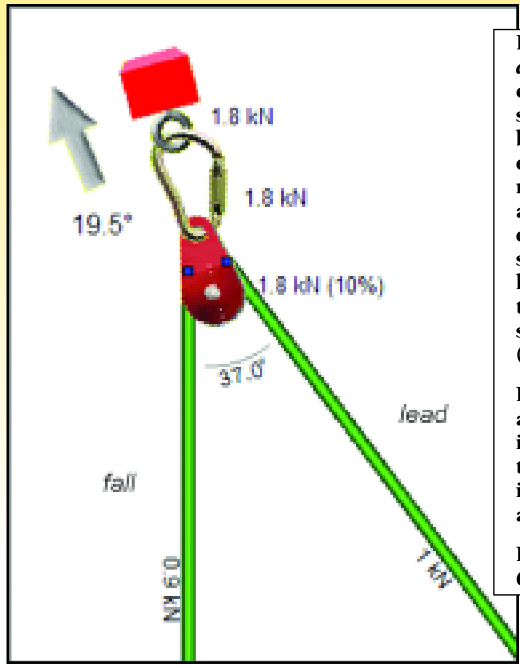

Figure 6. *Line forces shared at the block as the peak force occurs.* As the peak force occurs in the lead of the line, rope tension is not transferred equally to the fall, but is reduced by friction. A friction effort of 10 percent was assumed to be representative for rope running through a block when snatching logs of considerable mass. Friction effort would be significantly greater if referring to low loads or static friction, as, for example, the case when attempting to lift a load suspended from one end of the line (Donzelli 1999).

In combination with the effect of friction, an average line angle of 37 degrees results in a reaction force at the anchor point that reaches 1.8 times the peak force in the lead and acts on a vertical stem at an angle of roughly 20 degrees.

Illustration created with RescueRigger 6.0.

The deviation from the vertical direction generates a sideways pull on an upright stem, which causes it to bend under the peak force in the rope. Most climbing arborists have already experienced the resulting deflection of tree stems, giving them a ride in the treetop that is not always a joyful one. The forces generating this movement, a tree's reaction to the load, and the impact on the climber will be described in future publications or can be gathered from the final report.

According to the results of the kinematic studies, the log has not yet covered the entire distance of fall as the peak force occurs in the line. Furthermore, the log has not come to rest, but still has considerable speed. These results indicate that energy dissipation in rigging operations is more complex than assumed so far. How this may change current models to assess rigging forces is described in the final report and will be discussed in future articles as well.

As the log slams against the trunk, it finally will be stopped (speed zero) before it eventually bounces back. With this impact, energy is transferred into the tree, causing oscillation and, in some cases, even greater deflection of the stem than generated from the peak force in the rope. This instant may in some cases be a more critical phase for arborist safety because the forces acting on the climber could cause spikes to disengage from the stem or shake off a poorly positioned lanyard.

As a general rule, arborists should try to avoid shock-loads in rigging systems. However, because the occurrence of shock-loads cannot be completely excluded, safety margins during shock-loading events should be the reference for risk assessments.

Detailed visual tree inspection, appropriate worksite communication and organization, and using safe rigging strategies may help prevent accidents. However, it is vital to also correlate the bearing capacities of all components of the rigging system (including the tree) to potential peak loads in a worst-case scenario.

In the research projects discussed in this article, a number of parameters required to assess safety margins in rigging operations were studied. But the project also raised a lot of questions—for example, about the influence of cutting techniques and effects of damping in the tree. Future research should be undertaken to answer those questions.

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