

# Rigging Research

Article three in the series by Treevolution, in conjunction with Brudi & Partner TreeConsult (Germany), promoting the findings of the recent research project: An evaluation of current rigging and dismantling practices used in arboriculture. The research was published in 2008 and is available on the HSE website ([www.hse.gov.uk/research/rrhtm/RR668.htm](http://www.hse.gov.uk/research/rrhtm/RR668.htm)).

## Estimating forces generated in rigging operations

### Objective:

- to describe how peak forces occur in the rigging and which parameters may alter their magnitude and effect
- to provide improved means to assess log weight, which is the major factor for assessing peak forces

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 climbing arborists and their equipment, as well as the tree, to loads that are great in magnitude and hard to predict. If arborists could estimate the peak loads generated in rigging operations in worst-case scenarios, rope failure and other potentially catastrophic consequences might be avoided. Even if the rope did not break, it could be essential to detect whether safe working loads were exceeded and the rope should be retired.

The mechanical properties of ropes and slings, rigging blocks and friction devices may have a considerable influence on the dynamic process of rigging. Their flexibility and damping properties determine the peak force generated from stopping a log of specific mass. Their load-bearing capacity under an impact gives a measure for the maximum load the rigging should be exposed to, in order to avoid failure of any part of the equipment and to prevent rapid fatigue of cordage. Last but not least, the tree is also part of the rigging system. How it affects the process of a rigging operation and which loads it is exposed to has been investigated during the HSE rigging research.

Three basic questions need to be answered when attempting to gain more information about forces generated in rigging and dismantling operations:

1. What are the actual movements of log, rigging and stem that take place when a log breaks off from the hinge and subsequently falls onto a rope?
2. How is the energy dissipated in the rigging system, and by what means and to what degree do the different components absorb the energy?
3. What are the peak forces and maximum deformations that components must bear, and what factors of safety are required to allow for safe working?

As they had not been previously studied in detail, these issues were addressed in a series of lab and field tests during the rigging research. This article sets out to highlight some of the findings and turn the interest of arborists to the final report of the project which is available online.

There are many scenarios in rigging and dismantling of trees that could generate considerable forces. The greatest amount of kinetic energy will be set free when 'snatching' a stem with the rigging point below the log (also referred to as topping-down, butt-hitching or pole-rigging). During such operations, the friction device may become locked and not let the log run (snubbing off). This could occur either intentionally (due to limited space below the rigging), or accidentally (if wraps on the friction device fall over each other, or if ground persons either overestimate the log's weight or underestimate the friction generated by a number of wraps on a lowering device).

In those cases, the rigging, the tree, and, last but not least, the climber are all exposed to great forces. To date, only a few rules of



*In this scenario, the centre of gravity of the log (approximately at half its length) is above the rigging point (the block axis) which allows the section to freefall a great distance until the ropes starts to decelerate the log.*

thumb for assessing peak forces generated by rig-ging operations have been published. These tend to mirror the experience gained from a great number of rigging operations, and their application does not generally seem to pose any risks for standard dismantling operations. However, their validity could be compromised when applied to non-standard situations, including working with heavy sections and/or limited rope length. In such circumstances, they might not appropriately accommodate a worst-case scenario in which a section has to be blocked and cannot be gradually decelerated.

The study focused on this rigging scenario, while others are mentioned only briefly in the report, either by way of comparison, or to describe particular effects that can help to minimise the forces generated. The

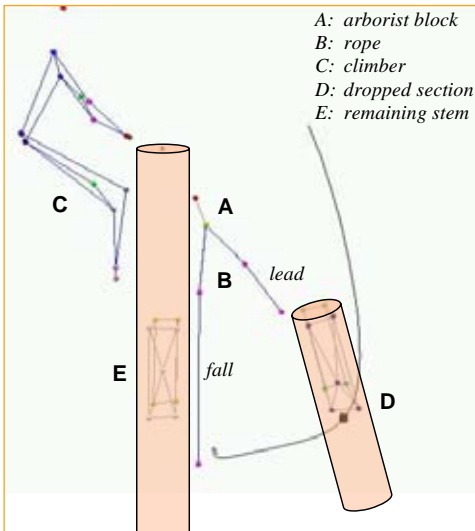
movement of log, stem and climber as well as the direction of the rope as the peak force builds up were tracked using motion capture technique. In the field tests it was confirmed that the log's flight path follows a specific trajectory where the peak force in the line is generated long before the log hits the stem.

The snatching operation was cut into 5 sequences according to the kinematics and the energy transformations prevailing during those intervals. Those stages are illustrated in Figure 2 on the basis of the trajectory of the log's centre of gravity.

1. As the climber pushes the log, the log pivots over the hinge, while the fibres 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 a vertical fall with a sideways component as a result of the form of the notch.
3. As the log is being stopped by the rope, the flight path's direction is diverted back towards 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.
4. The peak force in the rope occurs at the instant illustrated in Figure 1, when rope stretch and deceleration of the log both are at maximum. They generate a sideways pull on the stem due to the fact that the rope does not run parallel to the stem.
5. As the log hits the stem, violent oscillations may occur that could in some cases compromise the climber's safety. The log often bounces back a little and slowly settles down, stretching the rope due to its weight.

In field tests, 4 trees were dismantled while recording peak forces in the block and the stem reaction with a data logger and the movements of all parts with a digital video camera. The results were analysed and compared with the motion capture study. Distinct differences were found between snatching logs and tree tops. 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 downwards 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.

According to the results of the kinematical 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. During the rigging operation studied in detail, only 30% of the log's initial potential energy

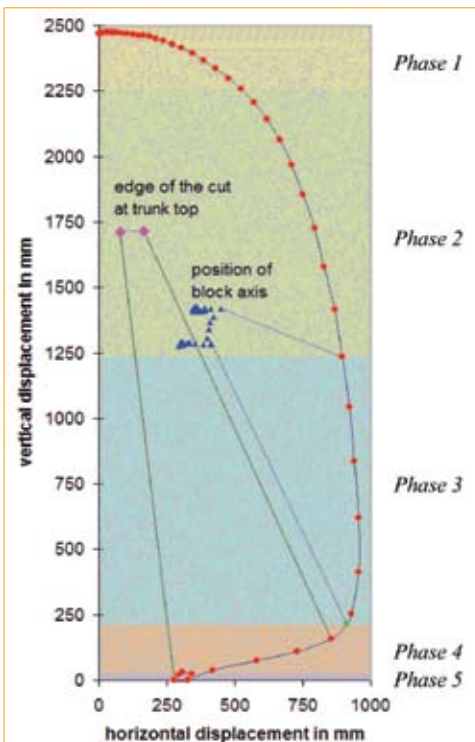


Motions of the dropped section, the remaining stem, the rope and the climber were recorded at a rate of 24 pictures per second. The log's centre of gravity followed a distinct flight path (black line).

The climber was pictured as a matchstick man due to markers that could be tracked at the head and joints of his body. The rigging rope was equipped as well in order to allow for recording rope angles and the stretch in both legs of the line.

This still picture captures the instant when the peak force is generated at the arborist block. At that time, the two legs of the line form an angle of 37° in average.

**Fig 1 Motion capture recording of topping-down a stem**



The red dots indicate the position of the log's centre of gravity at 42 ms (0.042 sec) intervals, which is a common shutter rate of standard film material (24 pictures per second).

In phase 1, the log slowly pivots over the hinge while the notch closes until the log breaks free. During freefall in phase 2, speed increases (indicated by larger distances between two subsequent red dots).

As phase 3 begins, the rope takes up load and 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.

Phase 4 starts after the peak force occurred (indicated by the bright green dot). Now, the stem sways back because the tension in the line is partially released (pink rhombus indicating the position of the cut).

In phase 5, the log finally hits the stem, causing vibrations before it bounces back.

**Fig 2 Kinematics in a 'snubbed off' rigging scenario of a log**

was transferred into the rope, causing it to stretch as it decelerated the log. Due to friction in the block, stretch was unevenly dissipated between the two legs of the line. Because friction concentrated the peak force in the lead of the line, it stretched roughly 15% more than the fall.

The test results illustrated in Figure 3 indicate that log mass was in fact the most important factor in assessing anchor forces. The forces in the block varied between 9 and 11 fold the log weight, with one outlier where a factor of 13 and one heavy section where the magnification factor was only little more than 8. From other experiments, some carried out by the late Peter Donzelli in the USA, and the present study it became obvious that flexibility and length of the rigging rope, the length of the section and damping effects will affect the peak forces significantly. Within the scope of the HSE rigging research, the latter could be demonstrated for top sections: When in leaf,

the aerodynamic resistance of the foliage reduced the peak forces by roughly 25%. It was also confirmed that letting the log run would minimize forces most effectively as can be seen in Figure 3.

The peak force is often assumed to be a fixed multiple of the log's weight. One rather widely-held belief, for example, is that the peak force at the block could reach about 10 times the log's weight in a snubbing off operation (as compared to the log being gradually lowered by a running rope). Despite the fact that many factors affect

the peak force in a specific scenario, the results of the field study confirmed that easy rules of thumb would have worked in the studied operations in which only one type of rope was used (double braid 14 mm polyester).

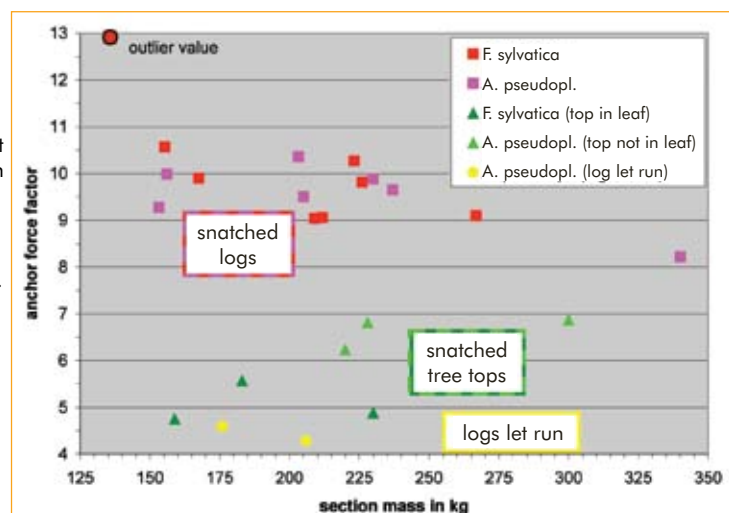
A simple rule of thumb would estimate the line forces when snatching logs as roughly 5 times the weight of the section. If it is assumed that the line force is doubled at the block, the results displayed in Figure 3 would kind of confirm this rule. But due to friction in the block and the angle among the legs of the line at the instant the peak force occurs, the actual line force was greater and varied significantly. By adding the equivalent of 175 kg to the fivefold of the weight (cf. blue line in Figure 4), this simple rule of thumb would have covered all but one outlier which had a mass of only 130 kg and therefore would not have been critical anyway.

Another rule of thumb that would cover all recorded line forces is shown as a yellow line in Figure 4. The validity of any of those easy estimations is limited to the range of mass which was included in the test as well as the diameter and type of the rope that was used. It must be emphasised that in order to adapt the results to other rigging systems it is required to take into account several parameters which are often hard if not impossible to assess in the field.

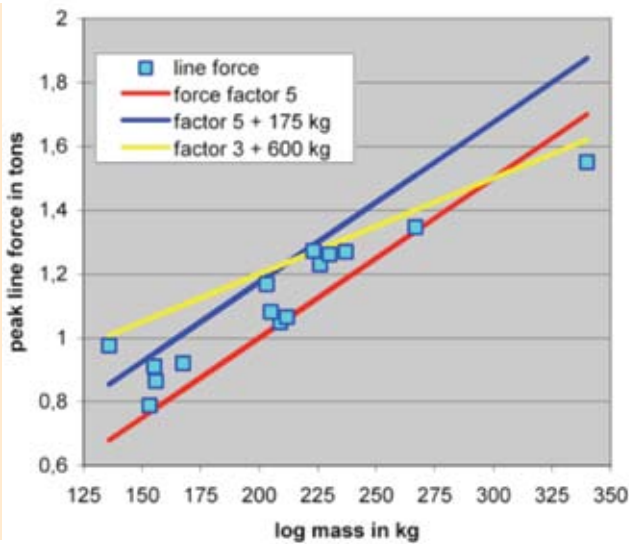
If mass is the most important indicator of peak forces, arborists should have access to easy means for estimating log weight and the mass of branches. A proposal for a procedure and the data required to carry it out were included in the rigging report. The calculation starts with measuring the diameter of the section at the cut or at the approximate centre of gravity (which is usually located somewhat beneath the middle of a tapered stem). Diagrams and tables may be used to assess wood volume and apply values for the specific gravity of the tree species in question. In a next step, the weight can be corrected for taper or present decay just as well as branching and leaves for crown parts.

There are several possibilities for assessing the volume of a tapered stem section. The volume of a cylinder may be multiplied by a form factor with respect to taper (this form factor is the ratio of minimum to maximum diameter). On the other hand, the estimation could be based on the volume of a cylinder of constant diameter equivalent to the average diameter of the log.

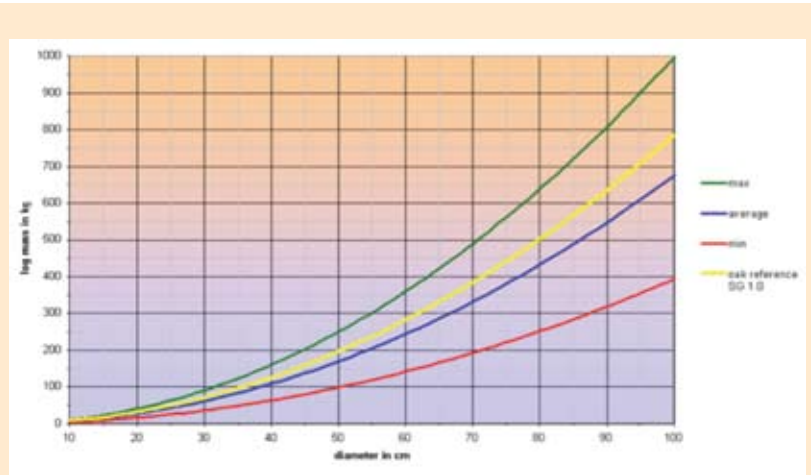
The best approximation would be to determine the volume of the frustum of a cone based on height and the maximum and minimum diameters of



**Fig 3 Forces at the block in a 'snubbed off' rigging scenario**



**Fig 4 Line forces from 15 snatched logs (14mm double braid polyester)**



**Fig 5 Log mass curves for 1m sections of green wood**

the log. However, this third method requires a more challenging calculation. Errors arising from choosing the second option do not exceed 5% as long as the log's diameter at the top is more than half the basal diameter. Therefore, averaging the diameters measured at top and bottom of the log seems to be a viable solution.

For many species, specific gravity of living fibres was collected. In tables, a representative value for density is provided in order to adequately assess the weight of a section. Yet it is also possible to use line diagrams which illustrate the effect of diameter on the volume and mass of a log of 1 m length and the given diameter.

As far as tree section weights are concerned, significant changes in weight can result from geometrical, physiological, anatomical or structural variations. The available data has usually been derived under standardised laboratory conditions. It shows strong deviations and variability within species. Therefore, any simple means of assessing the weight of a section is likely to be prone to wide deviations, and any such assessment will require safety margins of some degree to be built in to the calculations.

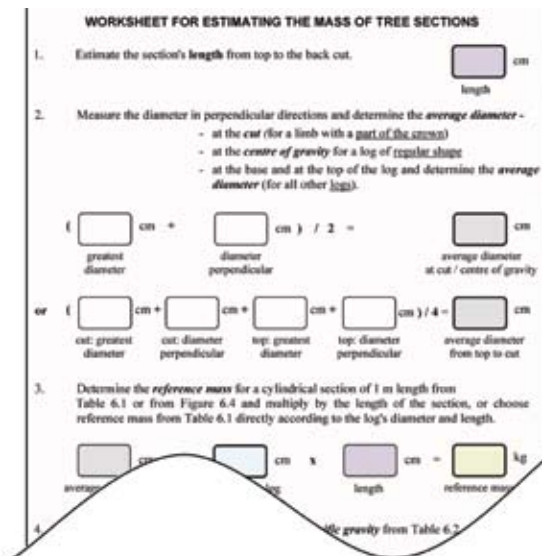
Finally, the rigging report proposes a process of estimating the mass of a section in a spreadsheet. If the log has a diameter of

48 cm at its base and 42 cm at the top, the average diameter would be 45 cm. The yellow reference line in Figure 5 indicates that a 1 m long section would weigh approximately 160 kg which is confirmed in Table 1. Multiplying this mass by the actual length of the log (e.g. 1.5 m) gives a reference mass of 240 kg.

This mass was derived from the estimated volume alone. To account for the species-dependent density of wood, a correction factor can be applied. In our example, the tree to be felled is a Silver Fir. According to Table 2, the reference mass could be multiplied by a factor of 0.84 which results in an estimated mass of roughly 200 kg. Table 2 also indicates that in extreme cases the mass could be up to 250 kg, in case the density really matches the maximum value found in literature. This inherent uncertainty must be addressed in any estimation. This strategy shall be discussed in the next and final part of this series.

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**Fig 6 Prototype worksheet for estimating the mass of sections**

length in cm	diameter of section in cm																	
	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90		
30	3.5	6	10	14	19	25	30	40	50	55	65	75	90	100	115	125	140	155
40	5	9	15	20	30	40	50	60	70	85	100	115	135	150	170	190	215	235
50	7	13	20	30	40	50	65	80	95	115	135	155	175	200	225	255	285	315
60	8.8	16	25	35	50	65	80	100	120	140	165	190	220	250	285	320	355	395
70	11	19	30	40	60	75	95	120	145	170	200	230	265	300	340	380	425	470
80	12	22	35	50	65	90	110	135	165	200	230	270	310	350	395	445	495	550
90	14	25	40	55	75	100	125	155	190	225	265	310	355	400	455	510	565	630
100	16	30	45	65	85	115	145	175	215	255	300	345	400	450	510	575	640	705
125	18	35	50	70	95	125	160	195	240	285	330	385	440	505	565	635	710	785
150	22	40	60	80	110	145	185	230	285	340	400	460	525	595	670	750	835	930
175	25	45	75	100	135	175	220	270	330	395	465	535	615	695	785	885	995	1110
200	30	55	85	115	155	200	250	310	375	445	520	600	685	775	875	985	1105	1235
225	35	65	100	135	180	230	290	355	425	500	580	665	760	860	970	1085	1215	1355
250	40	75	115	155	205	260	325	395	470	550	635	730	830	940	1055	1180	1320	1470

**Table 1: Reference log mass chart (green oak logs, SG 1.0) in kg units**

Botanic name	English name	Min	Median	Max
Abies alba	Fir, Silver	0.75	0.85	0.94
Abies concolor	Fir, White	0.77	0.82	0.88
Abies grandis	Fir, Grand	0.66	0.69	0.77
Abies procera	Fir, Noble	0.54	0.69	0.90
Acer platanoides	Maple, Norway	0.93	0.98	1.04
Acer pseudoplatanus	Sycamore	0.63	0.84	1.04
Acer rubrum	Maple, Red		0.80	
Acer saccharinum	Silver	0.72	0.72	0.81
Acer saccharum		0.90	0.93	
Aesculus		0.59	0.88	
Alnus		0.64		

**Table 2: Species-dependent log mass correction factors (excerpt)**

To highlight further the findings of the research project a Rigging Research Awareness Day was held on the 29 June in Beddgelert, Gwynedd, North Wales. A wide diversity of stakeholders from within the UK arboricultural industry were invited to attend the event, with the intention that they in turn would disseminate the information out to a wider audience.

The event was hosted by Treevolution, in conjunction with TreeConsult from Germany, and funded by HSE. Chaired by Liam McKeown, the Rigging Awareness Day opened with Alan Plom and Frances Hirst of the HSE making the opening introductions to some 50 delegates from all areas of the industry. They explained the thinking behind the day and highlighted that sadly this particular operation is the cause of many accidents within the industry.

Liam McKeown then gave his own talk on planning and managing rigging operations and best practice. He spoke of the appalling equipment he has seen in the course of his work, showing examples of distorted pulleys and lowering devices, buckled blocks, glazed and snapped lowering ropes amongst other items that had been misused. He also spoke of times when he had seen equipment being rigged incorrectly.

Andreas Detter, of TreeConsult, held the audience's attention with his presentation which included the kinematics of snatching logs and the forces generated, assessing anchor point strength, determining safety margins and tree dynamics when dismantling trees, and the effect on treeworker safety. His use of slides and videos helped to bring the report to life in a very understandable way. Andreas said, "It is good to have the opportunity to explain some of the information personally and through videos in a way that is just not possible through a written report, although the report is excellent and everything is there but is not so accessible or easily read."

After an informative morning session and lunch, it was onto the bus and off to the rigging site for some practical demonstrations.

The commentary for this section of the day was performed by Richard Allmond, with Chris Cowell, Paul Howard, Stuart Witt and Goronwy Hughes carrying out the practical demonstrations of removing sections from two large Noble firs. The systems demonstrated were tied off at the base (static not running) then sections were dropped on to a load cell at the top of the tree. Part of the afternoon was spent on visual tree inspection prior to rigging and magnitude of forces generated whilst rigging. Richard explained that the big question is going to be, 'What is the mass of the section being cut and how heavy will it be and when arrested, what are the peak forces that are generated?' Delegates were invited to give their best 'guess-timates' concerning length, diameter, weight and impact measurements prior to each section being cut. The delegates were

invited to work through an exercise on both trees to find the answers. Once the sections were brought to the ground it was possible to analyse the data and see how close they were, or were not!

Once everyone had got over their reticence at shouting out in case they were wrong, there were some pretty accurate guesses. Andreas provided some additional commentary and stressed the importance of continual assessment by the competent person whilst on site. Using software on a laptop Andreas was able to discuss the information recorded during the impact of the sections with the delegates in more detail. The middle section of the demonstration was on a much smaller stem showing some practical rigging set-ups for single line working, enabling the climber to get out of the tree safely and quickly.

Alan Plom, from the HSE, said, "Having the research report is one thing but to be able to put it over in a practical way and to have industry practitioners discussing it is really useful. We need these people to advise us where we go from here in terms of training needs. What we will do, through AFAG, is to produce clear practical guidance including detailed pictures. Having seen the demonstrations I think DVDs would be a useful tool but cost is always a major factor. It may be possible at some point to produce footage which is available on our website."

Liam was pleased that so many people from a wide cross-section of the industry had taken up the opportunity to attend the event. "At present you can only access the report via the internet, and as a result people are only aware of it in that form. Some people also think the report is all physics and are put off by this. People in this industry don't really want to sit in front of a PC screen at the end of a long day! As a result people are not getting a true picture of what the research report was about, so I was asked to arrange this event to present it in a more practical form."

With a good mix of contractors, trainers, consultants, manufacturers, suppliers, assessors, utilities and local authorities present, it was hoped that these people will pass on what they have learnt from the day. These are the very people who can help cascade the information down into industry. The message appears to be that everybody wants to see good practice being used in rigging operations. But it is not enough for everyone to just nod their heads in agreement. It is vital that meaningful standards and proper training are put in place to ensure the safety of all those who work at the sharp end!

Paul Howard of ArBo (Germany) at the top of a Noble fir waiting to be dismantled. Note load cell (kindly loaned by Noddy Knott of Treeworker) at rigging anchor point.



Top of fir is pulled...



Question: How heavy?



Andi Detter comes up with the maths! (Answer: 275 kgs)

Pictures taken at HSE Rigging Awareness Day held in Beddgelert, Gwynedd, during June 2010.