Rigging Research

Over the next few editions of essentialARB, Treevolution, in conjunction with Brudi & Partner TreeConsult (Germany), will produce a series of four articles 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).

Managing a Rigging Operation:

Introduction:

In 1998 when the Lifting Operations and Lifting Equipment Regulations (LOLER) and the Provision and Use of Work Equipment Regulations (PUWER) appeared, the arboricultural industry in the UK began to realise there were some new regulations to contend with. At about that time, I thought I had better make some enquiries, on behalf of my own business, as to what this Thorough Examination and Competent Persons terminology was all about...

I subsequently telephoned a company in Manchester that appeared to offer a service inspecting climbing and rigging equipment, and the conversation went something like this:

"How many cranes have you got?" was the first question from the voice in Manchester.

"Uh, sorry, none," was my reply.

"Platforms?"

"No."

"Other lifting gear?"

"Yes!"

I thought I was getting warmer...

"We have tree climbing and rigging equipment. Is that what you mean?"

"Mmm…"

I was beginning to realise that this wasn't going very well, so I enquired what was required of a 'Competent Person' (amongst other things) and what was the voice in Manchester going to do when he inspected our gear?

"Don't worry; we won't spike your ropes."

I assumed that he was planning on opening up the braid in our climbing lines with a Marlin Spike!

"Uh no it's ok," said I.

Then the million dollar question followed, after a few moments' silence:

"What do you arboreal types do then?"

That was it! I rapidly realised that I was contemplating employing someone from a construction safety company, who basically knew nothing about the tree industry and even less on what kind of equipment we used.

So, my reaction was to contact Ted Radford (who was the Technical Secretary for the Forestry and Arboriculture Safety Council (FASTCo) at the time), to enquire what Ted felt the arboricultural industry could do about this.

A few months down the line, a stakeholders' meeting was held at Myerscough College, and the plan was hatched to develop training and assessment of 'competent persons' from the tree industry, to carry out 'thorough examinations' of our 'tree' equipment. And that formed the basis of what we have today.

However, bearing in mind that LOLER and PUWER appeared in '98, we have only (as an industry) really dealt with Thorough Examination under LOLER. Certificates of Competence for Chainsaw Operators (a requirement under Regulation 9 of PUWER '98) have been around for a long time, and the arboricultural industry has developed Risk Assessment packages to meet the requirements of the Management of Health and Safety at Work Regulations 1999 (MHSWR), which I'll come back to later.

There are still a few holes, which the industry hasn't really come to grips with, so my intention is to try and help fill those gaps, using some of the information in Chapters 1, 3 and 4, from the Rigging Research.

Have a think...

Over the years, some of my work has involved me investigating personal injury claims, as what is commonly referred to as an 'Expert Witness'. One in particular sticks in my memory. A few years ago on a bright sunny day, two people were involved with taking down an old ash tree by a building. The climber had about 10 years' worth of experience, and the groundman had three weeks'!

The tree was being dismantled in sections, with a rigging pulley set high in the tree and a lowering rope wrapped around a friction device at the base of the tree.

The climber cut out one half of a Y-section of tree stem, hoping that the cut section would swing away from him and be lowered down to the ground. Unfortunately the climber (or groundman) didn't notice that the climber's rope had not been pulled through its anchor point prior to the 'rigged' section being severed with a chainsaw.

The groundman was watching, but unfortunately he was looking into the sun. (All he had to do was walk around the tree to see what was happening!) The large section was cut and when the piece fell it took the climber's line with it. The section of timber was held on the lowering device (which was rigged incorrectly and was, as a result, 'locked off') and the cut section was held, inverted.

JOB SHEET

EMERGENCY CONTINGENCIES

Fig.1 Cover Page - Site Specific

SITE-SPECIFIC RISK ASSESSMENT

Fig.2 Reverse side – Site Specific

The climber's line slid down part of the inverted stem and was held by a small lump of bark, thus stopping him hitting the ground.

Unfortunately the 'locked off' section was swinging level with the climber, and it impacted with him (more than once) causing him spinal injuries.

The groundman tried to release the lowering device and when he realised he couldn't, he then tried to reach the injured climber with a ladder with little or no effect. He had called the emergency services with his mobile phone, but he didn't know the location of where he was working. So they couldn't find him. He ran to the nearest road and stopped a farmer (who was driving his tractor), who then helped him call an ambulance...

When the incident was investigated the following issues (amongst others) were raised:

- No risk assessment had been carried out.
- There was little or no communication between the climber and the groundman.
- Training was inadequate.
- Equipment was not appropriate and was rigged incorrectly.
- There were no emergency contingencies in place.
- There was no prior planning.
- There were insufficient people on site.

Now I would like to have a look at the highlighted items listed above.

Risk assessment:
The only worthwhile risk assessment package for arboriculture in the UK (in my opinion) is the existing Risk Assessment for Commercial Arboriculture, which is delivered by the Arboricultural Association (www.trees.org.uk). The package utilises a site specific risk assessment which is supported by a generic risk assessment, amongst other things.
By all means it is not perfect, but it does work (for us anyhow), and it saves us having to reinvent the wheel!

However, when planning and carrying out rigging operations the following may assist us.

Imagine this:
A 65' Scots pine has been identified for removal. You've been asked to quote for the work and you have been successful. The tree is located in a residential area and is dying back due to root damage about five years ago (sound familiar?). There is an access drive, but it is very narrow. The tree is growing in the middle of a soft well maintained lawn. There are two 80' pines alongside the tree to be removed, and there are two manhole inspection covers near the base of the tree. You've decided to have the tree 'rigged' in sections.

Now, you use your risk assessment pro-forma for the proposed work, but is it enough?

Thinking back to the requirements of LOLER (beyond inspecting climbing gear), think about what else you need to consider.

You've priced the work, you've won the contract, but your job (mainly) is pricing other work and keeping your business going. This job will be fine for your 'tree gang' to do, without you, so you arrange a day with your customer to have the pine felled.

What is your role now?

In the Rigging Research two roles were identified: one as the Responsible Person, and the other as the Competent Person.

4:0 OPERATIONS

Completed by: I Bodsit
Position: Director
Date: 1st August 2008

Ref:	Hazard	Risk	Persons involved	Industry best practice/guidance	Date Issued	Control measures	[illegible]	Action Required	By (date)	Completed (date)
4.4	Branch removal	Cuts, impact/ crush injuries,	Climber, ground crew, client/general public	HSE INDG317 (Rev1) "Chainsaws at work"; AFAG Safety Guide 301, 401, 403, 308; "A Guide to Good Climbing Practice"; NPTC CS30, 38, 39, 40, 41	1/8/08	All operators trained and certificated. Correct climber position. Accurate severing cuts. Team communication. Work equipment, plant and machinery stored securely at suitable distance from tree. PPE. Client / General public excluded form work area	Yes	None	n/a	
4.5	Use of lowering equipment.	System failure, impact/crush injuries. Rope friction burns	Climber/ ground crew/	AFAG Safety Guide 301, 308, 401,403; "A Guide to Good Climbing Practice"; NPTC CS38, 39, 40,41. HSE AIS 30: "LOLER: How the Regulations apply to Arboriculture" Rigging Research *Evaluation of Current Rigging and Dismantling Practices used in Arboriculture 2008*	1/8/08	All operators trained and certificated. Equipment inspected regularly by a competent person. Thorough Examination of Lifting Equipment (lowering equipment every 12 months). Correct routing of ropes. Appropriate position and strength of anchor points, pulleys, etc. Working within Safe Working Load. Team communication.	Yes	None	n/a	

Fig.3 Generic – Dismantling

Job ref.__________
Date __________

Checklist prior to rigging operations

All ticks to be initialled when satisfied
RP CP

Off-site checks Complete Part A before proceeding to Part B

A
Has a Responsible Person (RP) been appropriately identified? (NAME ________) ✓
Has the work been clearly identified by the Responsible Person? ✓
Has a Competent Person (CP) been appointed and notified? (NAME ________) ✓
Has the work been identified and assessed by the Competent Person? ✓

B
Risk assessments
Has the appropriate generic risk assessment been referred to? ✓ ✓
Has a site-specific risk assessment been initiated? ✓ ✓
Does the site-specific risk assessment contain an emergency contingency plan? ✓ ✓
Has the need for any additional technical support (personnel or equipment) been considered? ✓ ✓

Manpower and supervision
Is there appropriate supervision for managing the rigging operation? ✓ ✓
Are there sufficient competent operatives for the emergency contingency plan to be actioned? ✓ ✓
Are all operatives competent to carry out their anticipated duties? ✓ ✓

Equipment & other resources
Has appropriate equipment for the operation(s) been provided/selected? ✓ ✓
Is there sufficient equipment for an aerial rescue to be performed if necessary? ✓ ✓
Has any requirement for additional technical support been satisfied? ✓ ✓

Communications
Are there feedback systems in place for both during and after the work? ✓ ✓
Do all operatives understand the importance of the feedback systems, and how they work? ✓ ✓

On-site checks Complete Part C before proceeding to Part D

C
Prior to starting the work
Do all operatives understand and agree with the risk assessment(s)? ✓
Have all the controls specified in the risk assessment been implemented? ✓
Has a safe strategy and system for the rigging operation(s) been identified? ✓
Do all operatives understand the strategy and system for the operation(s)? ✓
Can the work be done without the Responsible Person being on site or if not, is the RP present? ✓
Do all operatives understand the procedures for pre-use checks, set-up and operation of the equipment they will be working with? ✓

D
Prior to removing the first section
Has due consideration been given to the nature (weight, size, shape etc) of the section to be removed? ✓
Has due consideration been given to the risk and/or consequences of anchor and/or equipment failure? ✓
Have suitable aerial, landing and processing work zones been determined? ✓
Does the risk assessment cover the transport corridors between all working zones? ✓
Is each component of the rigging system correctly configured? ✓
Is each component of the rigging system compatible with its neighbouring components? ✓
Is appropriate supervision in place for the operation? ✓
Do all operatives understand their assigned duties? ✓
Has a communication system been agreed and understood by all operatives? ✓
Can all operatives communicate clearly with one another? ✓
Do all operatives understand their responsibility to STOP the operation if they believe that it could or has become unsafe, or if there is a change from the agreed plan, or if they are unsure about any aspect of the operation? ✓

NB All checks in Part D must be applied before the removal of each subsequent section

Fig.4 Checklist prior to rigging operations (p. 16)

The Responsible Person:

The Responsible Person (RP) would normally be the person that has plenty of experience in work like this. They've kept up-to-date with 'modern lowering methods' by attending refresher training courses and workshops, they keep up-to-date with current legislation, they may actually own the business and in this case, it's decided that the foreman can take charge of the work.

We'll now refer to your foreman as the Site Safety Co-ordinator or as the Competent Person.

The Competent Person

The Competent Person (CP) is now key to the whole operation. He or she must be charged with total responsibility for carrying out the work. Like the RP, they must have the necessary knowledge, training and experience to effectively manage and control the work as it's carried out.

There is now no need for the RP to be on site whilst the work is carried out, however he or she must be contactable if required.
Note: If you are self-employed, you may fulfil the roles of both RP and CP!

Now that the Responsible and Competent Persons have been identified a line of communication must be established.

If you refer to Figure 4, a draft checklist has been suggested. You will see that Section A will be completed by the RP, Section B involves both the RP and CP and Sections C and D will be the domain of the CP.

Communication & Planning

Example: What many contractors may try to achieve when they are pricing tree work is they will carry out a pre-risk assessment of the work site. If the customer is present, they may compare notes on potential site hazards. If the contractor is awarded the work, he or she will complete the site specific risk assessment and draw up a list of what is required on site. They should then endeavour to be on site prior to or when the work starts, and should transfer the information across to whoever will be the Site Safety Co-ordinator (CP). Both the RP and CP compare notes, and other suggestions may be offered by the CP. Once they are both happy with the outcome then the CP will go through the job with the climber(s) and groundstaff and again other suggestions may be offered. Once the whole thing has been agreed, then each operative may sign the risk assessment (RA) document to state that they understand what is required of them. And then they'll get down to carrying out the work.

In a 'rigging' scenario the checklist shown in Figure 4 may be attached to the RA. However, once completed, don't put it down and forget about it. Section D may need to be referred to on a regular basis.
Remember: The RA is a 'live' document and may require updating due to weather conditions and site constraints (for example).

Training and Certification

As you are most probably aware, we have a range of training and certification schemes/providers in the UK. However, there is very little to choose from when it comes to training and certification in 'rigging'. Training courses appear to range from two to five days in 'Dismantling Operations'. (The UK currently has no set standard for this specific type of training, which I find very worrying!)

Our industry standards for 'competence testing' are the NPTC Certificates of Competence (C of C's). The only C of C that we have specifically for Dismantling Operations is CS 41, which in my opinion is very basic, considering the findings of the research!

In my experience some people look at the pictures in magazines, buy some gear, cobble it together, try and obtain some guidance via e-mail(?), and then start cutting big lumps off! This may seem unrealistic, but have a look at the pictures above right. They are all genuine, and each one tells a story:
Photograph 1 shows a distorted lowering device and Photograph 2 shows a buckled 'rescue' pulley; 'exploded' arborist block and 'popped' stitching on eyesling.

So, back to the pine…

So far, in this scenario, we have dealt with PUWER, LOLER, MHSWR and now we have some more recent ones to contend with…the Work at Height Regulations (WAHR) 2005.

We can now take it that the Responsible Person has completed the initial paperwork for the dismantling of the tree; however, I have not covered how the RP has decided to have the tree felled. Will it be done from the ground, thus avoiding working at height? Will it be dismantled with a crane; a mobile elevating work platform (MEWP); or will it be done from rope and harness?

Photograph 1

Photograph 2

In Chapter 3 of the Rigging Research a flow chart has been devised to help select a Safe Rigging Strategy and System of Work. (See below, Figure 5)

A safe strategy would normally follow a Visual Tree Inspection, (which will be covered in the next article). What we now need to consider is how will the work be carried out?

With the Work at Height Regulations 2005, most tree workers are now aware of the risk assessment process for working at height. Bearing in mind the pine that is ready for removal, the CP would have considered the best method of work. Could it be felled in one? Not in this case! Could a MEWP be used? No,

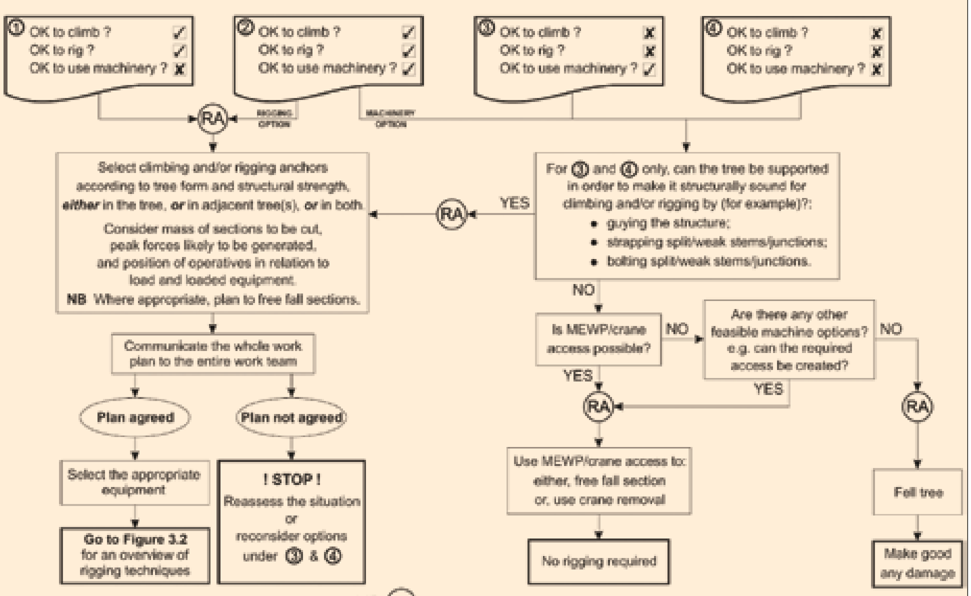

Fig.5 Safe Strategy flow chart (p.74)

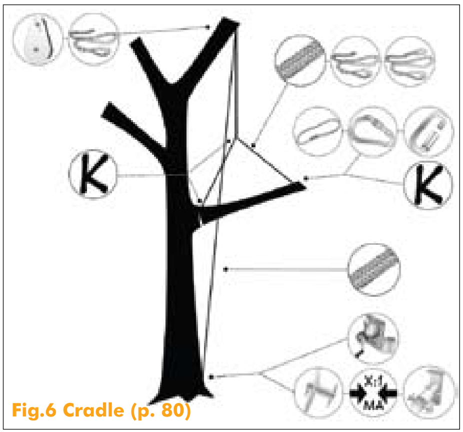

Fig.6 Cradle (p. 80)


Fig.7 GRCS winch (p. 78)

considering the soft ground, lawn and underground services. Could a crane be used? No, due to the restricted access, and soft ground etc.
So the decision is made to bring the tree down in sections, with a climber in the tree.

Selection of equipment

Unfortunately one of the most common tools for controlling friction when dismantling trees is the port-a-wrap style device. In my experience many contractors rely on these for all take-downs, no matter how big the cut sections are!

When I look at friction devices that have been so distorted; ropes that have been severely glazed due to heat build up; eye slings with 'popped' stitching; pulleys with bent pins and/or missing sheaves; and broken karabiners, it makes you wonder what severe loads were encountered on the tree, where the rigging pulley was installed!

If you carry out large take-downs, invest in a lowering bollard, at least. If you can afford it, buy one with a winching system that can enable you to pre-tension the lowering line and even lift timber. However, remember: if you don't need to 'rig' the tree, don't. That way we will minimise loading on our tree, thus minimising any risk to our climber, but we may have a bit more lawn damage to contend with!

In order to help our CP decide on the right equipment for the job in hand, Chapter 3 of the research has an extensive range of icons that support ten different tree dismantling scenarios. For example:
In Figure 6, I have selected a common scenario; that of a branch being cradled. In the five prompts listed alongside the diagram, terms such as "…centre of gravity of section to be removed"…"pre-load line to estimated mass of section"…and "minimise swing and impact loads" are used. These will be explored in future articles, but in the meantime cross-reference to Figure 8 will help the CP decide on whether the cut section should be rigged at all or what technique should be used.

The flowchart in Figure 9 will assist the CP in assessing issues such as "…peak forces…suitable anchors of sufficient strength…targets…communication" amongst other issues, whilst also emphasising the review of each operation before continuing.

So for the pine mentioned earlier, we've decided to go for a speedline, whilst working from a rope and harness. Factors that helped us make the decision were the obvious reluctance to damage the lawn, and the close proximity of the other pines, where we could secure the speedline from. We considered a 'floating lift' but we would have still damaged the lawn! Not sure what a 'floating lift' is? Have a delve into the research project!

Emergency contingencies

Think back to my story about the small team working in the ash tree, and the lack of provision for aerial rescue.
In the UK we have had basic techniques for aerial rescue documented since 1997. Since then training courses, Arboriculture and Forestry Advisory Group (AFAG) Safety Guides and Certificates of Competence have again been developed, but how often is rescue seriously considered, planned or even practised?

On one occasion I visited a contractor who was working in some big trees. They had an emergency access line in place, as per 'good practice' in tall trees, unfortunately it was secured in the same place as the rigging pulley anchor point, and when the climber was working up the main stem with a flip line, he inadvertently trapped the pre-installed rescue line, rendering it useless. Great in theory, but not so good in practice! Still, it was resolved in minutes.

So finally back to the pine. A rescue line will be placed in one of the trees located next to our 'target' tree, thus providing our 'designated rescuer' rapid access to our casualty. Just in case!

Summary

If you consider the scenarios I have mentioned in this article, I hope that more tree workers will think through each rigging job more thoroughly. By simple communication, use of appropriate risk assessments, obtaining decent training, selecting and using the right equipment, and proper planning (without cutting corners) we should avoid potential disasters and injuries. In my book, no piece of wood is worth being injured over, let alone killed!

Sadly, one more serious incident has come to my attention in the last two weeks, so it's still going on.

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Acknowledgements: Arboricultural Association, Treemagineers and TreeConsult.

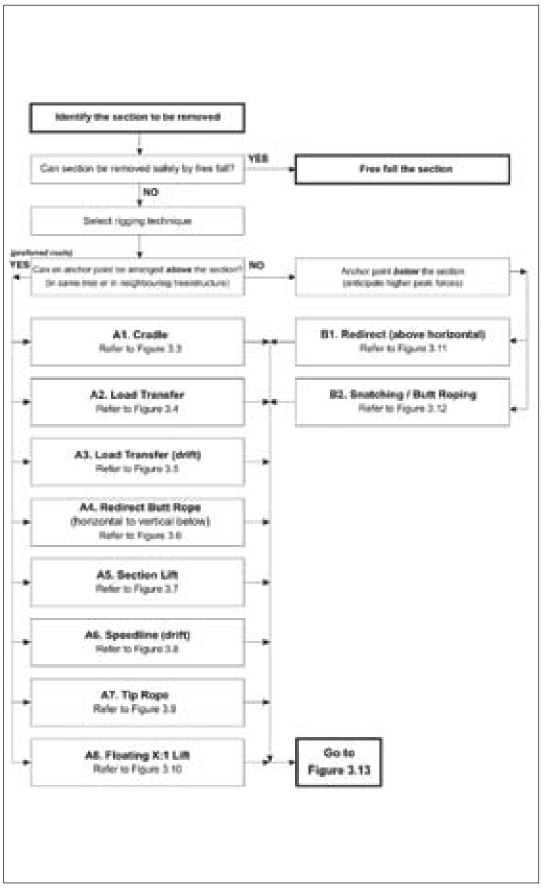

Fig.8 Selecting an appropriate rigging technique (p. 76)

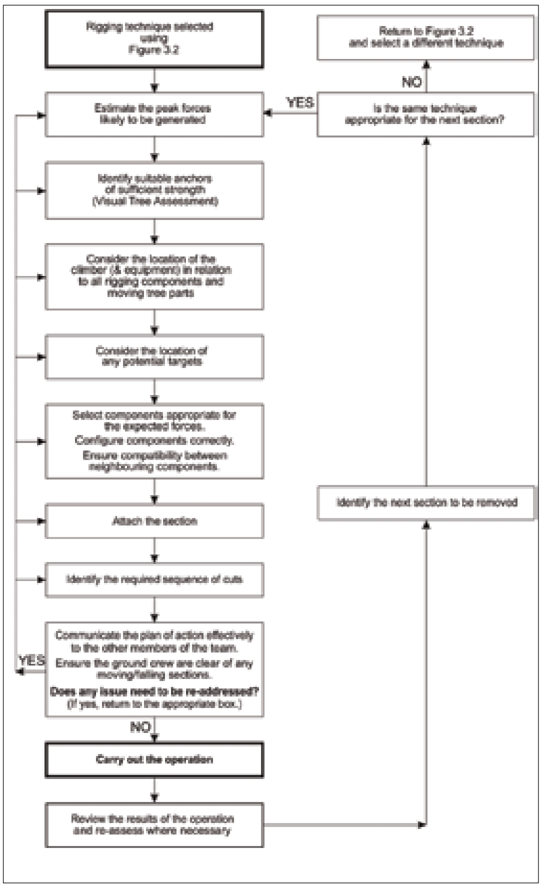

Fig.9 Carrying out an operation and reviewing the outcome (p. 85)

Rigging Research

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Inspecting trees and anchor points prior to rigging

The objective of this section of the series is to introduce the concept of red flag indicators in the form of pictures and descriptions, and to illustrate the required competence to carry out a risk assessment on the strength of anchor points used in rigging.

Introduction

Arborists are often called on to dismantle trees which show significant defects and are presumed to be likely to fail. Yet in regular climbing and rigging operations, those very trees may be used as anchor points to belay the climber or lower sections of wood. However, it is difficult to provide a clear answer on whether a certain defect makes a tree unsuitable for climbing and rigging loads, as the forces generated vary a lot and are usually much lower than the wind load a tree would experience in a storm.

The HSE Rigging Report lists some definitions which are essential in this context:

- Defect – a visible sign that a tree has the potential to fail (Meilleur 2006)
- Hazard – disposition of a thing, a condition or a situation to produce injury (HSE 1995)
- Risk – the chance of something adverse happening (Lonsdale 1999)
- Risk assessment – combines magnitude of hazard, probability of occurrence and the likelihood of damage to result from such incident

In essence, a risk assessment may very well conclude that a certain defect does not pose any risk for a climber during a dismantling scenario, even though the tree may be seen as a hazard in a storm event. In order to enable arborists to carry out such risk assessments, a proper understanding of the probability of failure is required which takes into account the severity of the defect and the loads imposed on the compromised part of the tree.

Methods

The Rigging Report provides a number of common symptoms for defects in the load-bearing parts of trees and made the attempt to tag them with indicators for increased and great likelihood of failure during rigging operations. The system of yellow and red flag indicators was used by Dwayne Neustaeter, a Canadian arborist, in his study guide.

There are a number of potential reasons for failure of structural parts of a tree which also apply to arborist safety. Among them are:

- strength loss due to biotic effects (e.g. fungal decay, wood-boring insects)
- abiotic damage (lightning strike, sunscald, severed roots)
- poor structural development (included bark, poor grafts, weak anchorage)
- previous failure (tilted root plate, over-bent branches, cracks)
- insufficient load-bearing capacity (inappropriate diameter, long lever arms, dead branches)

Besides this, there are other hazards in trees that are not related to failure of the anchor point, but should just as well be considered in a risk assessment, like dead major branches that could come loose, overgrown objects in the stem, stinging insects, harmful animals, vines and other objects suspended from the tree as well as electrical conductors running through, or in the vicinity of, the crown.

The following system of key steps can be applied to visual tree inspection prior to rigging and dismantling operations, with regard to structural defects and failure of the tree as a load-bearing structure:

- rank the overall susceptibility of the tree species for failure of tree parts. The Rigging Report provides a list of species that are regarded as structurally weak.
- identify compromised tree parts (branch, major crotch, stem, roots) and the magnitude of hazard.
- consider structural characteristics of the tree (tree form and development, stem inclination, pruning history, incremental growth).
- assess the potential loading of the compromised tree part in a rigging system (e.g. used as anchor point, redirect or main support, subjected to unilateral bending, torsion or compression).
- evaluate the likelihood of failure during the prospective rigging operation, eventually by probing the stability with simple load tests.
- evaluate the risk for climber, ground personnel and property.
- check if loading can be avoided, or if appropriate remedial measures can be applied.
- determine whether the tree is safe to climb and dismantle using standard practices, or consider the use of advanced techniques or machine-supported felling.
- continue visual inspection while climbing and dismantling/rigging.

Symptoms for risk of failure ...

In the following, a number of symptoms are presented as an example of situations arborists may encounter during a visual inspection prior to climbing or dismantling a tree. The choice is not random, because it focuses on severe defects, but the possible range is definitely not limited to the selection made for this paper.

... in the root zone

A tree's anchoring strength may be severely compromised for example by previous failure of the root-soil-matrix. The fact that the anchoring roots have already failed makes it very hard to assess the remaining load-bearing capacity of the root system. Generally, if failure has occurred in major parts of the load-bearing structure, the tree should be neither climbed nor rigged without appropriate measures to minimise the risk. Determining which measures could be taken requires a high level of competence. Any inherent risk of failure during dismantling should be avoided by rather choosing an appropriate working technique (see part 1 of this series).

Decay in structural roots or root severance close to the stem may also destabilise trees to a degree that the risk of failure is not tolerable. With regard to stability in wind, the distance of the damage to the stem base and the tree's reaction to the damage are important factors that allow for an assessment of the likelihood of failure. The area around the stem up to a distance equivalent of 1 to 1.5 times the stem diameter is regarded as a critical zone by some authors. Root severance in that area or

Tilted root flare of a spruce tree – A raised root flare and cracks in the soil indicate primary tipping failure. These trees may be very unstable.

root decay that was not compensated for by the tree should be regarded critical to stability and a thorough risk assessment is required.

There are a number of decay fungi which should be considered to indicate a great risk of failure when attempting to dismantle the infected tree. The Giant Polypore *(Meripilus giganteus)* for example is a frequent pathogen on beech and has often resulted in whole tree failure. A poor state of the crown and the absence of strong buttress roots underline that the infected tree was unable to compensate decay by putting on additional wood in compromised

Meripilus giganteus at roots of beech – The fruiting bodies of the Giant Polypore appear at a rather small distance from the stem. But the stem base shows an increase in diameter, due to compensation growth and formation of buttress roots.

This tree could be dismantled using climbing techniques, if no other symptoms for structural defects are present. However, other techniques should be preferred or (as a precaution) loads from rigging operations should be reduced as much as possible.

areas. The likelihood of those trees to fail is much greater than if the formation of reaction wood has taken place.

Fruiting bodies that are formed right at the base of the stem are usually more significant than further away from the stem. Some species are more susceptible for decay generated by specific fungi – and may be compartmentalised for a much longer time by another tree species. It is understood that Ustulina *(Kretzschmaria deusta)* is able to cause a quickly progressing rot in Linden trees, where it has caused failures during

Kretzschmaria deusta on birch – The fruit bodies of Kretzschmaria deusta on birch indicate extensive decay at the stem base and a great likelihood of root damage. There are no visible signs of adequate compensation growth.

The load-bearing capacity of this tree is severely reduced and loads generated from dismantling operations might lead to failure.

rigging operations, whereas it appears to affect stability to a lesser degree in beech trees for example.

... along the stem

Whether or not a compromised stem is sufficiently strong to sustain the load it is subjected to during rigging operations depends on the diameter, geometry and integrity of the stem, the material properties of sound wood tissues, the presence of compensation wood and, most importantly, the actual forces generated from rigging.

With regard to purely visual assessment, it seems important to state that critical stages of decay, where residual walls become very thin and mechanical failure under comparably small loads may occur, are often indicated by the presence of several symptoms like dead bark, growth depressions, crack formation, inrollings or seams and fruiting bodies of wood-decaying fungi. Accordingly, signs of compensation growth, strong wound-wood formation around cavity openings (often indicated by growth striations), hint at a lower degree of strength loss.

Even proponents of conflicting methods of tree diagnosis agree that compensation growth, e.g. by the formation of wound-wood tissue around the opening of a cavity, acts as a reinforcement and restores some of the strength loss caused by decay in central parts of the trunk. If pathogens are able to break wound-wood barriers and to infect adjacent areas of the stem this will usually indicate a greater failure potential due to an advanced destabilisation.

Hidden cracks may be indicated by rib-like protrusions as well as grooves, both eventually showing signs of wound-wood formation. Generally speaking, fresh cracks without wound-wood can be considered more hazardous, because they are likely to propagate through the wooden body, along the fibre grain, when load is applied. Cracks generated some time ago may be surrounded by newly-formed tissue that may be able to stop the crack propagating. However, it has also been observed that old cracks, especially if they have never been entirely closed by wound-wood, may open up again under extensive loads.

The load-bearing capacity of a stem with a radial crack is significantly diminished where the crack reaches from one side to the other. One-sided longitudinal cracks of limited depth (such as many lightning scars) hardly reduce the strength in bending, provided the stem is loaded in a direction parallel to the direction of the opening. However, crack propagation and reopening can present significant hazards.

Especially in the advanced stages of decay, some fungi species are able to cause a significant degradation of wood strength in limbs and stems. Failure during climbing operations was reported on an advanced infection of birch by *Piptoporus betulina*. In such cases, wood fibres were found to be severely degraded, even though they did not visibly appear to have altered greatly.

... in branches and branch unions

Cracks in a junction indicate that failure has occurred when the fork has been

Conks and bark damage around a cavity in Celtis – The stem of this Celtis would not have had sufficient strength to withstand an estimated wind load at speed 12 Beaufort, according to results of a pulling test (Elasto-Inclinomethod).

Despite the strong formation of wound-wood next to the cavity, and the increased diameter at the base, the tree exhibits cracks in the bark on the right side (see arrowhead), indicating damage to the cambium and a thin residual wall at the stem base. In these cases, it is essential to carefully examine the amount and spread of sound wood fibres in the cross-section of the stem.

Fresh crack through the stem of beech – If cracks are found on both sides of the stem, the load-bearing capacity may be significantly reduced (by more than 50%).

If rigging loads have to be applied, precautionary actions are recommended, to prevent failure due to longitudinal splitting.)

exposed to excessive loads. Crotches have to dissipate the load from two or more limbs and, therefore, often have to bear greater stress than other parts of the crown. Included bark acts like internal cracks, because notch stresses are concentrated when the fork is loaded in tension.

Crack in branch union, horse chestnut – The load-bearing capacity of a cracked fork may be so much reduced that failure could occur when the limbs are loaded.

In some cases, the initial strength of the union may have been so great that even the separated halves are strong enough to support fairly low loads from climbing or rigging operations.

But without reliable tests on how much load the compromised structure can bear, and without precautionary measures to mitigate the risk of failure, it would be irresponsible to use such a stem as an anchor point (akin, for example, to using a karabiner with a crack in its metal).

Fracture is most likely on branches where decay has reduced the residual wall to a thin shell. These hazardous cross-sections are usually detectable by a dull, hollow sound, when using a mallet. Inspection from the ground may not reveal the likelihood of failure, especially in species that are anatomically capable of sustaining their crowns with only a small number of active annual rings (e.g. ash, horse chestnut, willow, oak).

Thin-shelled branch on oak – Thin-shelled cross-sections are susceptible to failure under impact loads and torsion stresses. If the residual wall falls below 4 cm thickness, they are often detectable with a mallet.

At the same time, further symptoms like little diameter growth, bark damage, woodpecker holes and conks usually become visible at such an extent of decay. Both sapwood and cambial layer may be dysfunctional and prone to penetration by pathogens.

Depending on the ability of the species to compartmentalise infections, woodpecker holes and conks can be signs of extensive decay, as can growth depressions, bark damage and cavities. If such symptoms are present, visual inspection focusing on the integrity of anchor points is required to identify hazard branches. For this purpose, the use of binoculars may sometimes be necessary. If further inspection is required, primary anchor points that are considered to be safe could be used to access the canopy, in order to more closely investigate the bearing capacity of other potential anchor points in the crown.

Mechanical failure decreases the strength of branches significantly. Split forks may leave the remaining co-dominant structurally weak (strength loss of 75% in the direction perpendicular to the split). Similarly, horizontal cracks in solid cross-sections, arising from radial delamination of fibres in an upward bent branch (hazard beam), are associated with a reduction in strength greater than 50%.

Split branch ('hazard beam') – The strength of this delaminated branch will be roughly 50% of the intact cross-section (according to static calculations). However, even smaller loads may result in failure due to crack propagation.

Assessing the strength of natural anchor points in trees

If the visual inspection does not indicate symptoms for structural damage in a potential anchor point, the question remains if it is adequately strong to sustain the load it will be exposed to during the dismantling operation. In order to address this need, a model derived from statics analysis may be used. The tree or a branch is compared to a cantilever beam that undergoes unilateral bending. In that model, the compressive strength of marginal fibres is decisive for load-bearing capacity.

On the scale of wood fibres, excessive compression causes permanent deformation that is referred to as primary failure. The ultimate load-bearing capacity may actually be greater than the compressive strength, but the tree would be damaged long before fracture. Green wood is reported to be about twice as strong in tension as in compression. Therefore, failure will occur on the compression side first, by the buckling of fibres. Even though the structure will not fail completely when the fibres kink, the tree may not withstand future loads, even if they are significantly lower. Therefore the compressive strength of fibres parallel to the grain should be used as a threshold for strength.

The Rigging Report presents charts for the bearing capacity of tree stems that were designed using specific settings: a straight, upright stem; a standard height; and a standard load angle between peak forces and vertical stem axis. The standard height of the anchor point was assumed to be at 10 metres. The rigging operation that the charts refer to is snatching logs off a vertical stem. This scenario is defined by parameters derived from kinematic studies which will be discussed in the following part of this series.

The maximum sustainable load is displayed in Figure 1 (below) for five different groups of tree species, containing a range of 31 tree species common in the UK. They are based on values listed in the 'Stuttgart Strength Tables' which are commonly used in tree statics and were grouped for tree species of similar compressive strength. The under-bark diameter of a lime *(Tilia)* to be dismantled is determined as 33 cm at 1 m height (e.g. diameter with bark 37 cm, minus 2 cm bark at each side). The peak force this stem could bear, when a section of the stem is snatched from an anchor point at 10 m height, would be the equivalent of approximately 2 tons mass (19.6 kN force).

Open cavities and decay columns can be taken into account in some of the formulae used to assess strength loss. Practitioners might find difficulty in applying strength loss calculations to derive reliable figures on which to base a risk assessment. Particularly in severely damaged structures, with open cracks or decayed wood tissue, there would be no value in advising a strength loss calculation. However, where visible symptoms indicate that the tree has reacted to structural defects, simple assumptions for strength loss could be made.

In order to assess the strength of limbs and branches, tests were conducted in the course of the Rigging Research (with additional finances provided by the TREE Fund). Forty branches of four different tree species were pulled to failure. Seven mature trees were dismantled in the course of the study, including three roadside and four park trees.

The diameters of tested branches ranged from 7 to almost 30 cm at the trunk. During the destructive tests, the stress at primary failure was determined. The results show that living branches have a

Structural failure of a thin-shelled cross-section – A collapse of the load-bearing geometry is called structural failure. It is usually much easier to identify, as significant delamination cracks are often visible. It occurs only on trees that show severe structural defects like extensive decay when residual walls are reduced to a very thin shell, as it is the case in this picture.

tolerance to further loading. By permanent fibre deformation, the branch can take up significantly more energy even though the structure may be considerably damaged. During the next loading it may be prone to failure at much lower forces.

The yield stress derived from field tests is shown in Table 1. During another series of tests that followed the field study, yield stress values were derived for another 6 tree species. Values found in literature for other species were also included in the table if the test set-up and the diameter range included in the dataset seemed appropriate.

The unit Megapascal (MPa) can be visualised in an example. A horizontal

Species	Mean Yield Stress (MPa)	Diameter Range (cm)
Acer platanoides	24.5 / 33	5 - 30
Acer pseudoplatanus	35	8 - 26
Acer saccharinum	24	14 - 35
Betula pendula	27	5 - 12
Fagus sylvatica	32	7 - 19
Fraxinus excelsior	33 / 36	6 - 12
Gleditsia triacathos	36	-
Platanus acerifolia	33 / 56	-
Populus canadensis	37	11 - 24
Quercus robur	27	5 - 19
Robinia pseudoacacia	40	-
Salix alba	29	12 - 16
Tilia vulgaris	25 / 29	9 - 30

Table 1 Strength of wood fibres in branches.

branch of 10 cm diameter at its base is sustaining a mass at 90 cm distance. The stress in the marginal fibres will be critical, if the mass in kg is 10 times the yield stress value indicated in MPa, i.e. for lime (yield stress 25 MPa) the critical mass would be 250 kg.

Figure 2 Example visualising the stress unit MPa for branches.

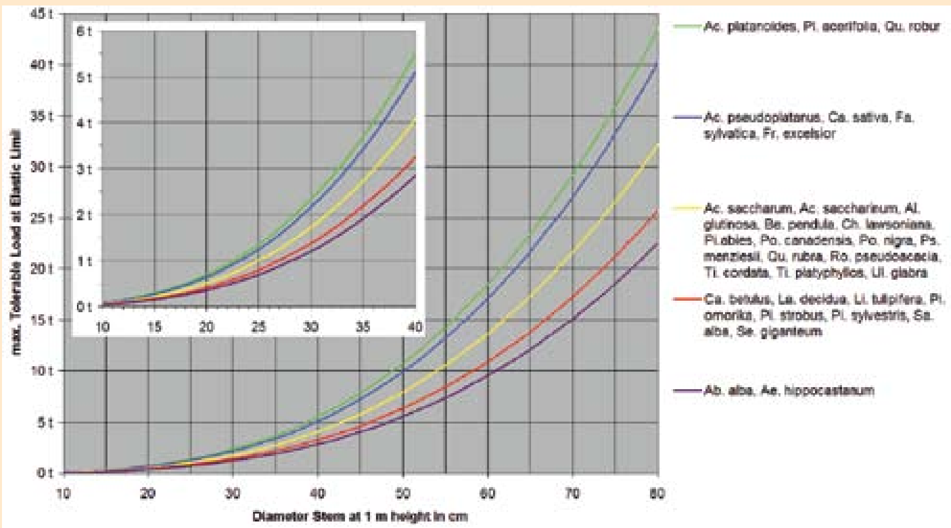

Figure 1 Load-bearing chart – single anchor points (insert: zoomed low range).

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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).

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.

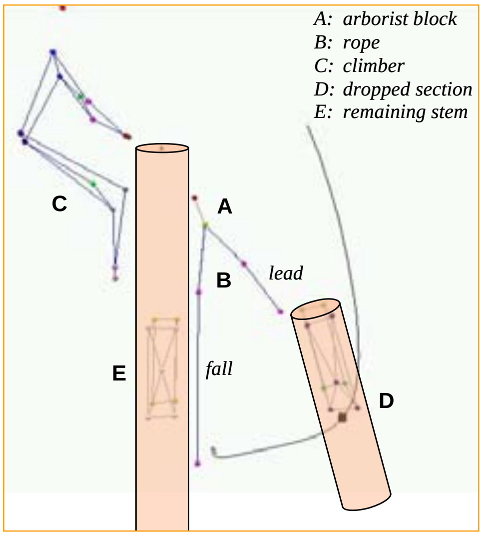
3. As the log is being stopped by the rope, the flight path's direction is diverted back towards the stem. At the same time, the stem is being pulled forward and the block slides down the trunk until the anchor sling grips tightly.

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

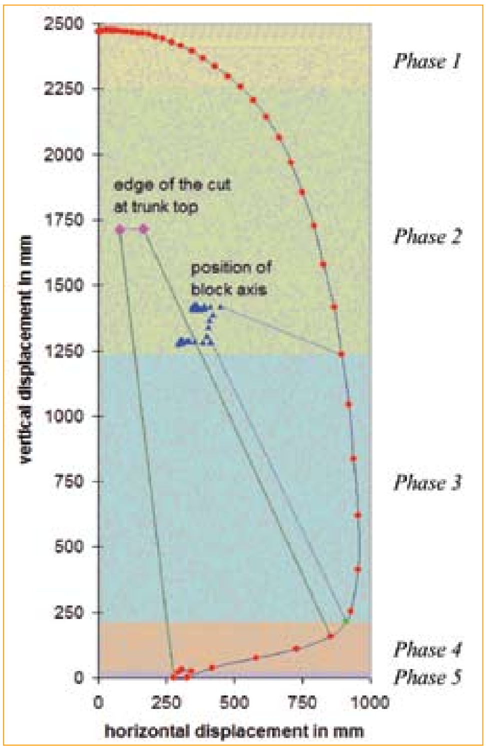


Motions of the dropped section, the remaining stem, the rope and the climber were recorded at a rate of 24 pictures per second. The log's centre of gravity followed a distinct flight path (black line).

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

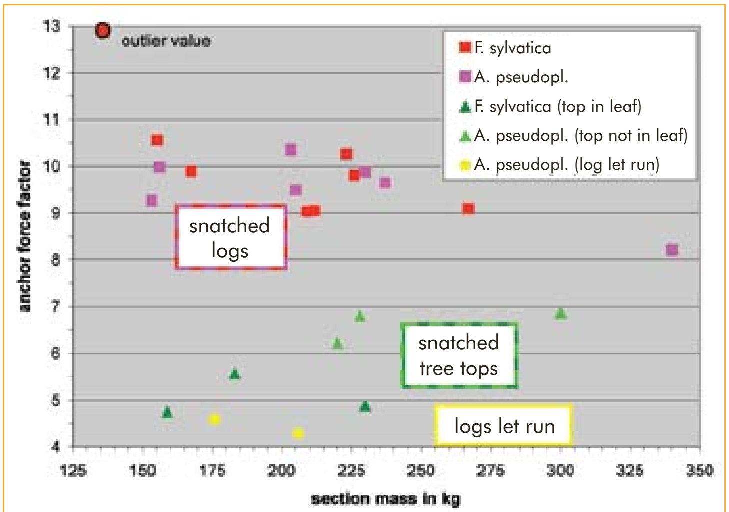


Fig 3 Forces at the block in a 'snubbed off' rigging scenario

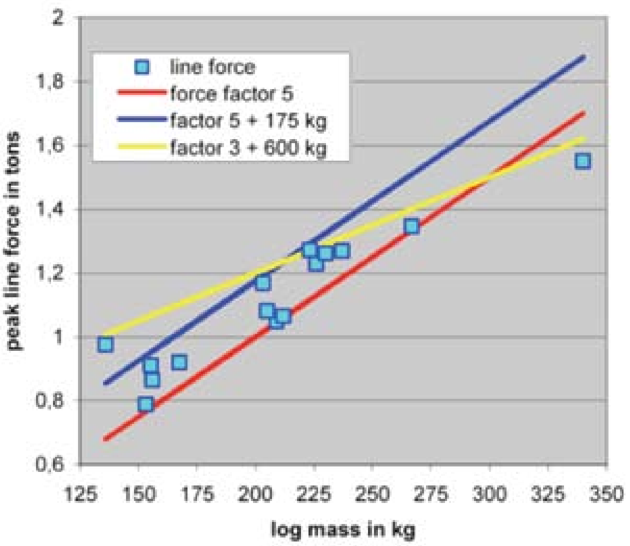


Fig 4 Line forces from 15 snatched logs (14mm double braid polyester)

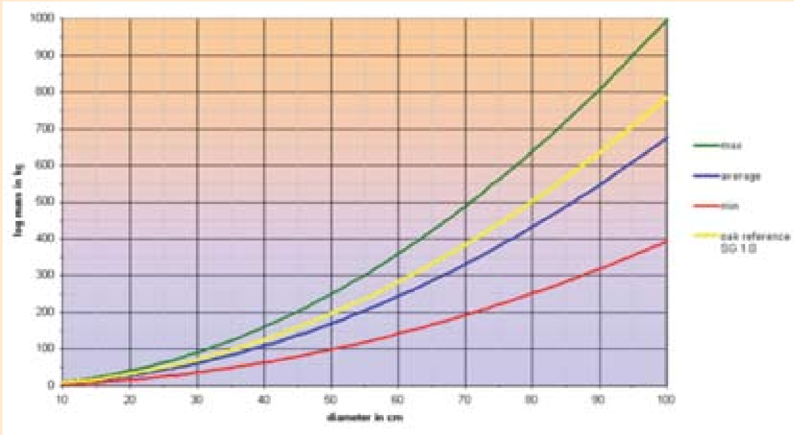


Fig 5 Log mass curves for 1m sections of green wood

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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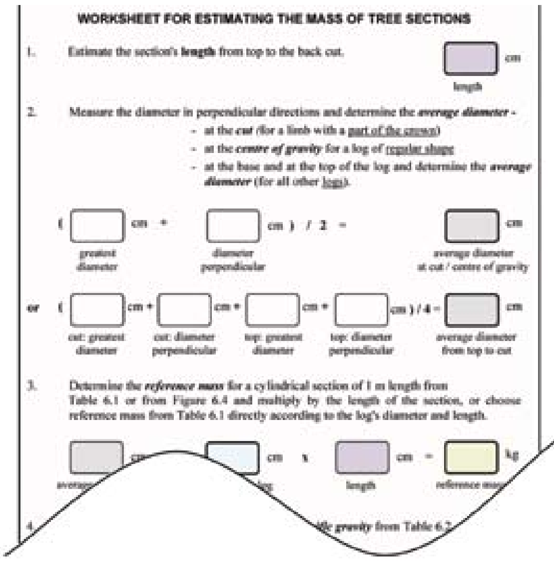


Fig 6 Prototype worksheet for estimating the mass of sections

length in cm	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
20	3.5	6	10	14	19	25	30	40	50	55	65	75	90	100	115	125	140	155
30	5	9	15	20	30	40	50	60	70	85	100	115	135	150	170	190	215	235
40	7	13	20	30	40	50	65	80	95	115	135	155	175	200	225	255	285	315
50	8.8	16	25	35	50	65	80	100	120	140	165	190	220	250	285	320	355	395
60	11	19	30	40	60	75	95	120	145	170	200	230	265	300	340	380	425	470
70	12	22	35	50	65	90	110	135	165	200	230	270	310	350	395	445	495	550
80	14	25	40	55	75	100	125	155	190	225	265	310	355	400	455	510	565	630
90	16	30	45	65	85	115	145	175	215	255	300	345	400	450	510	575	640	705
100	18	30	50	70	95	125	160	195	240	285	330	385	440	505	565	635	710	785
125	22	40	60	90	[illegible]	155	200	245	295	355	415	480	550	630	710	795	885	980
150	25	45	75				[illegible]	295	355	425	500	575	665	755	850	955	1065	[illegible]
175	30	55						345	415	495	580	675	775	880	995	1115	1240	
200	35								475	565	665	770	885	1005	1135	1270	[illegible]	
225										635	745	865	995	1130	1275	1430		
250										[illegible]	830	960	1105	1255	1420			
											[illegible]	1080	1215	1380	[illegible]			
												[illegible]	1325	[illegible]				

diameter of section in cm

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 saccharinu[illegible]	[illegible] Silver	0.72	0.72	0.81
Acer sacc[illegible]		0.90	0.93	[illegible]
Aesc[illegible]		0.59	0.88	
A[illegible]		0.64	[illegible]	

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

Rigging Research

Article four, and the last 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).

Mitigating the risk of failure during rigging operations

Objective:

– to illustrate the concept of sufficient safety margins in all load bearing components

– to provide safe strategies for mitigating the risk of failure

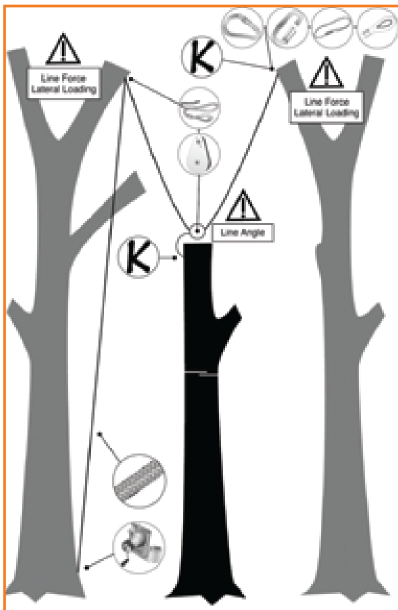
– to demonstrate the effects of rigging operations on climbing arborists and how to avoid potential risks of injury

The hazards involved in rigging, and the potential consequences for the climber, are significantly greater in number, and higher in risk, than those arising in most other arboricultural operations. Therefore, in order to undertake operations safely, a different level of experience, training and individual work planning is also required.

A competent person should be able to avoid worst case scenarios if possible by setting up rigging systems that allow for minimising forces in the rigging and loading of natural anchor points. A number of different set-ups have been illustrated in the HSE Rigging Report. To only show one out of many drawings, Figure 1 depicts a system named 'Floating X:1 lift'. By using two adjacent trees, even severely weakened trees can be dismantled without inflicting great loads upon their structure. Yet it is essential that the competent person is aware of the risk involved in overloading the anchor points in case the angle of the line gets rather flat.

In order to assess whether a specific rigging system is appropriate and sufficiently safe, a safe strategy should include consideration of the strengths and properties of the equipment used, such as ropes, slings, pulleys and friction devices. The condition of the equipment (age, wear and damage), and the specific way it is intended to be used in a rigging system, can alter its load-bearing capacity (e.g. knots tied in a lowering rope). At the same time, the specific configuration of a rigging system will determine the load its components will be exposed to (e.g. the angle that the two legs of the rope form at a pulley block, the total length of rope used in a rigging system). Safety considerations should always be based on a worst case scenario.

These considerations are best explained by the example of ropes used in dismantling trees. Arborists are aware of the fact that rope manufacturers specify design factors for their products which define the working load limit. Despite the fact that the strength of an unused rope is 55 kN for example (a measure equivalent of the weight of roughly 5 ton mass), the working load limit is set at 20% of that, i.e. 11 kN or roughly 1 ton.



1. Identify mass of section and lateral forces on anchors.
2. Consider method of attachment and support section (beware high forces arising from large angles between legs of line).
3. Apply load to line until section is lifted/moved to desired location.
4. Manage speed of descent of section.
5. Relocate section to landing zone.
6. Minimise swing and impact loads.

Drawing by Mark Bridge, 2008

Figure 1. Floating X:1 Lift .

This precaution is intended to provide sufficient safety margins in typical applications for this type of rope. Design factors are chosen with regard to several unknown parameters, in terms of both the actual strength of the material in a certain configuration (e.g. knots in a rope, with a certain bend ratio) and its condition at a certain state (e.g. age, wear, abrasion). However, especially with regard to impact loading, manufacturers have stated that standard design factors do not apply.

The term 'design factor' is often used as equivalent to 'safety factor', implying that any rigging system that adheres to recommended design factors will actually produce an equivalent safety margin. As a matter of fact, a design factor of 5 for a rope does not guarantee that, in a given rigging scenario, the rope will be able to carry 5 times the load it is exposed to. Simply by forming a knot in the rope, it may lose 50% of its original strength (thus reducing the effective factor of safety to 2.5). Taking into account a typical degree of wear, another reduction of at least 20% might be expected. This would render the rope's actual strength as being only twice the recommended working load limit. Should such a loading actually occur, the safety margin in this scenario would be 2, and not 5 – as it may be presumed.

If it is possible to assess the effects of knots, wear and ageing on rope, as well as to estimate satisfactorily the loads they will be exposed to in rigging scenarios, safety margins might be adequately assessed. In the former part of this series, the estimation of forces in rigging was discussed. With regard to the components of a rigging system, results of the Rigging Research shall be presented in the following.

Nevertheless, each consideration will bear a degree of uncertainty, which further emphasises the need to incorporate appropriate factors of safety in any calculation.

Based on tests carried out by Ken Palmer of ArborMaster and Michael Tain at Samson Ropes in 2004, strength loss in knots was determined for rigging ropes and slings of different kind and diameters when attached to tree stems. More than 20 configurations of knots were pulled to failure, using more than 15 samples of cordage. Some findings are illustrated in the following.

Typical knots used to attach the rope to a log were studied, among them half hitch with a running bowline, clove hitch and cow hitch.

In the test lab, logs were fixed and the knots were set in a standardised manner. The ropes were pulled to failure and the peak forces were recorded.

Knot set-up at log (half hitch with running bowline).

The results differed from rope to rope, due to the structure of the rope, its material and diameter. The variation for a single knot like the running bowline could range between as little as 15% strength loss and almost 45% of the rated strength of the rope for the type of rope most commonly used in dismantling, a double-braid polyester rope. This strength loss occurred almost regardless of rope diameter.

Studies of drop tests carried out in the course of this project showed that a considerable length of rope (7 to 18 cm) slips through the half hitch when load is applied to the attachment. The greater the log's diameter, the more rope is wrapped in a loop around it, increasing the total stretch under a given force (despite the effect of friction). A larger diameter log may, therefore, result in more rope being pulled through the supplementary hitch. In some cases during the tests, as much as 30 cm of rope was found to have passed a half hitch during a worst-case shock loading.

Considering the fact that great peak forces may be acting on the rope in such scenarios, it is possible that rope-on-rope friction could severely damage the rope. This may explain why the supplementary hitch, as shown in the lab tests as well, weakens the attachment. At the same time it enhances its stability, which is the primary reason for its use in this situation. The strength reduction observed is the price paid for the benefits gained by using supplementary knots: better control over log rotation; a tight and stable grip; steady loading of the primary knot; and protection against knot slippage or unravelling.

In slings as well, strength reduction due to knots should be considered. Here again, different knots and rope types come into play. Generally speaking, the often used dead eye slings seemed to be less strong when configured than endless slings (e.g. Whoopie/Loopie type). For dead eye slings made from Samson Tenex, a high performance fibre, strength loss in cow hitch or timber hitch ranged from 15 to 30% for diameters above 16 mm. Smaller diameters seemed to be stronger in the timber hitch, which may result from the tighter grip of the rope at the entry point in the cow hitch.

Ropes undergo changes in strength

The yellow-green marker identifies the original position of the rope's point of entry to the half hitch.
Note the visible abrasion of peripheral fibres on the left side of the rope after exiting the half hitch, indicating damage due to rope-to-rope friction under great load (red arrow head).
The rope used was a 14mm double-braided PES line (Buccaneer Bullrope).

Slippage through a supplementary half hitch.

as a result of wear, changes in condition, and degradation (e.g. due to abrasion, dirt, moisture, UV light exposure etc).

Manufacturers only determine material properties for new and unused rope. As long as reliable data on strength loss in arborist ropes remains unavailable, the required factors of safety to determine safe working loads can only be derived from experience.

The Guide to Good Climbing Practice prescribes an inspection of ropes, prior to climbing, in order to detect cuts, frays, glazing, poor condition of eye splices, contamination and other defects.

Unfortunately, precise data on gradual strength loss of arborist rigging lines, due to increasing age, degrees of wear or damage to a particular extent, is not available. Impact loads will speed up the decline of a rope's strength more than loads generated by lifting and winching operations. In operations that involve fall arrest, failure under shock loading may occur after relatively few load cycles.

A test carried out at Teufelberger, Austria, led to failure of a kernmantel

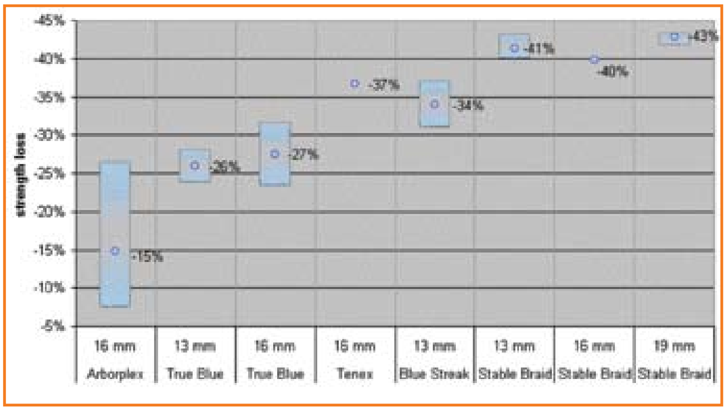


Figure 2. Half hitch with running bowline (average strength loss indicated.)

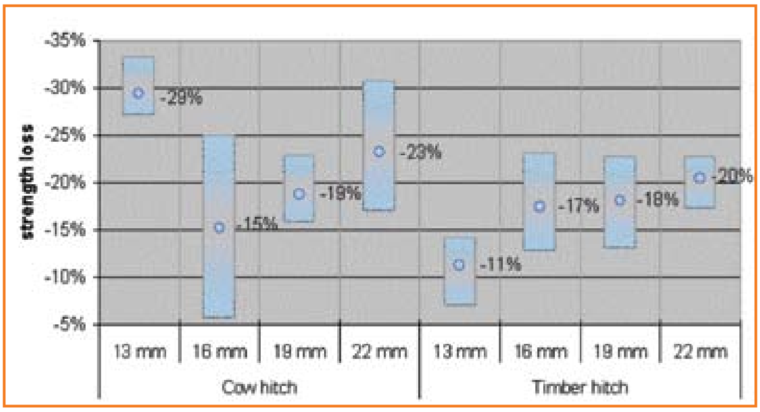
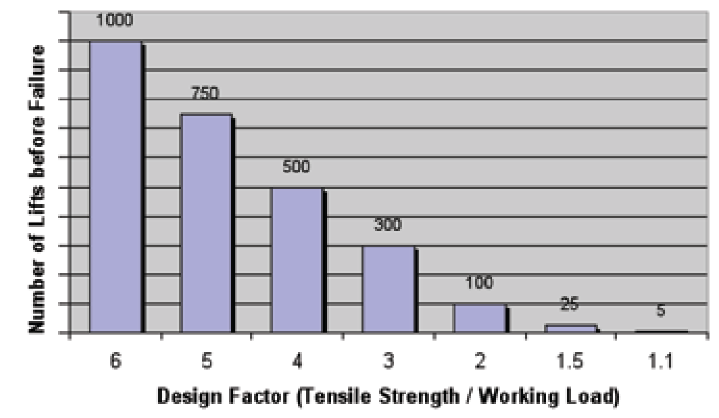


Figure 3. Strength loss in Tenex eye slings tied to a log.



A publication cited by Don Blair illustrates the effect of repeated loading on the strength of a rope. Even if the load is applied gradually in a lifting operation, loads that exceed one third of the rated strength reduce the life span of rope to less than one third.

Figure 4. Cycles of failure (data taken from Blair 2000).

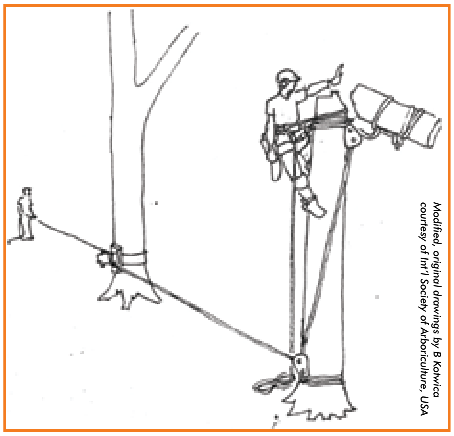


Figure 6. Adding more rope to the rigging

rope after 14 impact load cycles that generated forces of less than 40% of its rated strength (design factor 2.5).

Arborists should always include the possibility of unexpected shock loading, and its potential consequences, in any work plan that they develop for a rigging operation.

This can be done, for example, in the following ways:

- by careful system design, incorporating appropriate correctly configured components (in order to minimise the likelihood of accidental shock loading occurring).
- by cutting shorter sections, and using appropriate cutting techniques (in order to reduce the magnitude of the forces that equipment, tree and climber are exposed to).
- by proper work positioning, communication and site organisation (in order to prevent injuries and other consequential incidents arising from an unexpected failure).

Furthermore, it would seem to be essential to ensure that the rope is the weakest link in a rigging system, as recommended by a number of authors. In the case of failure of an item of equipment other than the rope, the energy stored in the intact rope could otherwise turn any failed hardware component into a deadly projectile. That is not to say that the recoil of a failed rope is without risk, but it may well be the lesser of two evils.

In the HSE Rigging Report, a worked example demonstrates how the concept of sufficient safety margins can be incorporated in risk assessments prior to undertaking a rigging operation. When configuring components for a rigging system, the maximum size of logs to be lowered should be limited by the forces generated in a worst case scenario, i.e. the blocking of the friction device resulting in an impact load.

If sufficient factors of safety are considered for all estimations, the required safety margins with regard to the strength of the rope could be significantly lower than standard design factors, which do not necessarily reflect the numerous parameters involved in rigging operations.

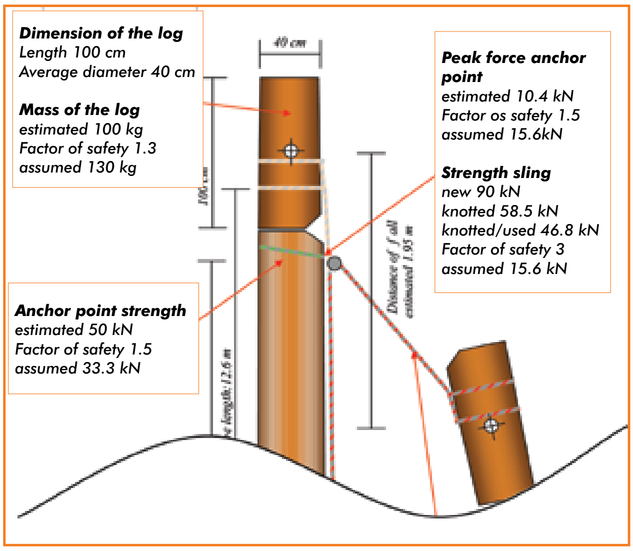


Figure 5. Worked example of a rigging system.

Current working practice is not always set out to minimise forces in the rigging system.

Arborists often trust in the strength and reliability of the equipment, not considering that it is often not designed for shock loading. By letting the section run, impact loads can usually be avoided. Nevertheless, there are cases where they might occur.

The level of competence required to adequately assess the effect of such rigging operations on the material as well as the climber is often greatly underestimated.

Yet several techniques to reduce forces in the rigging systems have been developed and are currently being used. Additional rope could be added to the rigging system by mounting a second arborist block at the base of the tree being dismantled and redirecting the line to the friction device installed at an adjacent tree.

The additional block at the base is essential to avoid overloading the anchor point: should the fall be connected directly to the friction device at another tree, the direction of the two legs of the line could correspond as the peak force occurs, thus increasing the lateral force on the anchor point.

Furthermore, leaving side branches on the section to be cut as well as on the remaining stem used as an anchor point has a great potential to reduce peak forces and minimise the resulting deflection of tree stems due to damping effects.

This benefits the climber as well who will not experience the usual ride in the tree top that is not always a joyful one.

Keeping forces to a minimum will enhance a climber's safety, because stem bending will be reduced. But, more importantly, it also helps in minimising the impact of a log on the stem which may well be the most

Taking the top out on a cleaned up stem.

In this tree, all lower branches were removed before taking out the top instead of leaving at least some side branches on. This procedure usually results in significantly higher stresses in the stem as well as much more violent sway reaction.

Those vibrations may be strong enough to even cause the spikes to lose their grip in the wood. This usually occurs at the instant when the top hits the stem in case the top is not let run.

critical stage for a climber's safety on solid, sound stems. Slender stems generated great deflections, and the impact of a large section could even lift a climber off his spikes. Log dimensions should therefore be kept as small as practicable when snatching sections off a vertical stem.

However, proper work positioning and belaying is essential in any dismantling operation, so that the climber is suitably prepared to deal with unexpected impact loads, and able to minimise any consequent effects. Generally speaking, a second anchor point attached above the climber (e.g. in an adjacent tree) would be the best safety backup. This would also help to minimise body vibration and prevent loss of grip with climbing spikes. If the climber's weight can not be supported from an anchor point above, a position of about 45° to the side seems to be advisable to be able to dissipate the stem's swaying movement.

Deadwood present in the crown of co-dominant leaders was observed to be a potential hazard as well. Stem vibrations could cause small branches to break loose. Although failure of larger diameter branches was not observed, this cannot be excluded, particularly in view of the potentially strong oscillations induced by shock loads in the rigging and by the impact of heavy logs on the stem.

Within the scope of the rigging research, it was not possible to definitively determine best practice. This is due to the lack of statistically approved data, the great natural variation in a range of parameters, the complexity of the structures involved, and the absence of reference data that could be drawn upon. At the present state of development, essential parameters, that require evaluation in rigging scenarios for safety reasons, have to be assessed from experience and limited base data.

Yet, a basic understanding of the concept of sufficient safety margins may improve an arborist's ability to adequately configure safe rigging systems with regard to a worst case scenario. It may encourage climbers to deploy strategies that minimise forces in the rigging system and thus mitigate risks involved in rigging operations.

It is certainly not desirable that arborists be forced to carry out a calculation of safety margins. However, the approach has gathered information for guidance to be provided, for issues requiring further study and for improved training and hazard awareness to be promoted among arborists.

Climber in a lateral position belayed from above.

The climber is able to support his weight from the second anchor point in an adjacent tree. Therefore the violent vibrations of the short and thick stem did not pose any hazard.

Yet this belay technique poses the problem of still having to attach a lanyard, in order to obtain correct work positioning, to the tree to be dismantled which may be severely compromised and prone to failure.

This is the last in the series of articles promoting the findings of the research. For further information visit www.hse.gov.uk/research/rrhtm/RR668.htm.

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