Life on a line

A manual of modern cave rescue ropework techniques

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The book is published in three parts, as divided below. This is part 1. It should not be read or republished in isolation from the other parts, to which important references are made.

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This book has taken about 3 years to put together, from the initial concept to the version you are reading here. I would like to thank those whose research over the last 40 years has made this text possible, and the countless thousands of cave rescuers and sport cavers whose never-ending quest for the unknown drives us all to push the limits, and walk away from them safely.

Dave Merchant, North Wales, March 2002

1. Introduction

1a. The reasons behind this book

There is nothing new about a book on caving ropework and indeed I am indebted to the early authors of such texts for both starting my personal interest in the sport and highlighting the need for this particular book. Almost everything that has been written about ropes, knots, pulleys and their use underground relates to the sport of caving – implying a single bodyweight and often scant regard for issues of legal liability and safety. Equally, almost everything that has been written about rope rescue relates to the world of sun-baked American cliff faces, skyscrapers and mountains. The problem that faces the modern cave rescue team is trying to adapt information from both of these often-unsuitable sources into something that works for them. *Life on a line* is an attempt to plug the gap, offering up-to-date information on rope rescue specifically intended for use both underground and in the UK, where legal requirements (and the availability of equipment) differ greatly from the USA.

This book contains very little that is actually 'new', as in the world of ropework almost everything that is possible, feasible or downright absurd has been tried, used and abused for as long as cavers and climbers have regarded the instruction manual as just another part of the packaging… The main problem for rescue teams, sport cavers and indeed for anyone writing a book on the subject, is that despite the massive commercial, legislative and amateur interest in ropework there remains almost as many points of contention as there are ways of tying a knot. Simple scientific facts such as the melting temperature of nylon are known absolutely. Issues such as the correct choice of knots or the best type of rope are areas with some argument but where strong weights of opinion have formed what almost amounts to a final decision. In areas such as the longevity of ropes or the best choice of drop tests the committee is out, shouting loudly and exchanging blows in the car park. Dramatically polar viewpoints have equal weights of evidence (or lack of it) to back up their side and anyone approaching without detailed knowledge can find it impossible to follow the discussions, never mind pick a solution.

What I have tried to do is draw together as much information as possible that is directly useful, edit out what is not and draw the best conclusions from the areas where nobody seems to agree. For clarity where evidence is based on my subjective conclusions it is made clear and the arguments explained as far as space and the onset of boredom will permit. Obviously, as time passes, many of these areas will be ruled upon by others - either by progress in testing or obsolescence - and readers leafing through a dusty copy in many years to come must of course refer to recent sources if they exist.

Having said all that, this book is not intended to become a training bible or any 'standard operating procedure', despite such a thing not actually existing in the UK of 2001. If rescue teams decide to adopt the techniques I have described then let it not be said anyone forced them into it. Beyond the rather select world of cave rescue, the techniques in this book should be of interest to surface and industrial rope rescue teams, plus sport cavers themselves who wish to know a little bit more about the limits they can push their equipment towards and still make it back for tea.

The book obviously includes extensive testing and reviews of equipment from several manufacturers. I do not pretend that the lists are exhaustive by any means, and I have intentionally concentrated on equipment in current use by cavers and cave rescue in the UK. I have no commercial interest or bugbear about a particular device or manufacturer, and any good or bad comments herein are based on the results of testing and experience alone. Equipment develops rapidly and by the time this book reaches you there will undoubtedly be another few sparkly anodised ways of spending money that we should have talked about. Such are the limitations of the printed word.

A significant amount of data has been taken (with revisions where needed for rescue loading) from the Health and Safety Executive Contract Research Report 136/2001, 'Industrial rope access – investigation into items of personal protective equipment' written by Lyon Equipment Ltd for the HSE and published in November 2001. Copies can be obtained via the HSE website at http://www.hse.gov.uk by searching for the report number. It is the most complete attempt at cross-comparison of equipment yet undertaken and deals with both physical equipment (ascenders, etc) and the rope/knot/protection system. If only it covered rescue loads!

I am also indebted to the many engineers, independent manufacturers and cavers who have spent time over the years measuring and recording what to many would seem pointless sets of numbers.

Disclaimer

Caving, climbing, rescue and work at height are by their nature dangerous and a risk to life. Techniques described in this book must be applied in conjunction with appropriate training, experience and supervision. Use of any procedure or technique described herein is entirely at your own risk. The publishers and author disclaim all liabilities, including but not limited to third party claims and expenses, for damage or injury resulting from negligent, inappropriate, untrained or incorrect use of any such techniques.

"An idea is never given to you without you being given the power to make it reality. You must, nevertheless, suffer for it." *Richard Bach*

1b. Rescue vs. recreation

Cave rescue is a complex process in detail, though from the viewpoint of a sport caver can appear far less confusing than it can to the average member of the public. However taking the widest-scale view of a rescue the process is remarkably simple: one or more casualties must be found and recovered by one or more cavers going into the same system and doing a better job than they did. Looking back to the early days of cave rescue in the UK (1950-1960) this was in many cases as advanced as things got. Cavers were rescued by groups of other cavers whose sole plan was to follow them down, find them and pull them out by some means that would be thought about when they got to it. Running a rescue in the 21st Century is a far more professional affair, as indeed it should be. However the pressures of a professional response come tinged with the issues of legal liability, safe working practices, insurance, training and competency… the list continues. Added to these 'internal' pressures on the rescuers are the associated external pressures from the media, regulating bodies and the need to provide all this with often inadequate charitable funding. The results can often be that a team's legal and financial responsibilities are dealt with as required, but the internal issues of training, rescuer skill and confidence are left somewhat behind. The result is that team member skills relate to callouts and their sport caving interests (and hence personal experience) rather than the sort of national standards adopted by 'surface' emergency services. UK cave rescue has evolved over a considerable time and the legal issues shaping teams are a comparatively recent factor. I would not advocate a rigid national training structure akin to the Fire or Ambulance services as the caving world has always operated on a more individual basis. However it is likely that the modern world of instant-reaction media and litigious 'clients' may well force such a framework. This is already beginning, with legal requirements on team member medical qualifications coming into place as I write. This book was written to try and narrow this 'experience-based' skills range but is not intended as any form of national training manual. It would simply be useful for someone in a rescue team to be able to look up the strength of a knot or the friction of a hauling system without having to go to the levels of research I have found myself wading through…

Cave rescue does have one distinct advantage over surface agencies such as the Fire Service in that in almost all cases the rescuers are also active sport cavers. It can be argued that this should be a mandatory prerequisite for joining the team. In contrast rope rescue services offered by the Fire and Coastguard agencies almost always rely on 'occupational' training and practice alone. As rope rescue plays a small part in the modern UK Fire service, it is clear that there can be problems of inexperience or memory amongst personnel. Personal discussions with Fire Service rope rescue teams and instructors confirm these feelings. Within cave rescue I will assume (and hope) that all rescuers are capable of ensuring their personal safety underground, can use all normal 'sport' techniques such as SRT, and therefore only need training in the specific extra techniques of rescue.

This book concentrates on the ropework and rigging associated with such rescue. It does not include medical, management or search techniques (such books exist via the MRC publications system or are in the pipeline by others). It is also not a book on how to do 'personal caving', as that is territory well trodden by countless authors before me. However before launching into the details of knots, pulleys and bolts it is important to define some ground rules for the overall structure of a rescue. We need to define the reasons for using ropework before we can establish the best way of doing it. What follows is a synopsis of a rescue and the parts thereof, based on the best current *suggestions* for methods and standards. I must stress that as of the time of writing there is no national policy within the UK for these methods (despite several attempts to generate one) and this is based on methods used in the USA, mainland Europe and Australasia. Here, it seems, progress has been more fruitful.

1c. Rescue loads

Throughout this book I will use the phrases 'rescue load' or 'rescue-rated' to refer to ropework that is capable of operating with the increased forces of a rescue, but we had better define them before we start. We also need to define some limits for other factors such as falls, loads on anchors and those on the casualty. Naturally with rescue it is not easy to limit your loads in every case, but the following definitions are difficult to exceed without realising it. If your team is forced into dealing with a very heavy load then you must revise your methods accordingly. If you end up with 500kg hanging on a single line, you must revise your will to live.

A rescue load (casualty or equipment) is defined as 200kg.

In early editions of this section there was some debate over the size of this figure and how it relates to number of people and so on, so I've reworded it.

A figure of 200kg derives from *two* possible combinations, and is based on the common methods of rigging used by UK cave rescue teams:

a) One 70kg casualty, one 70kg rescuer (barrowboy) and 60kg excess of equipment
b) Two 100kg casualties

This does not include an excess ratio (SWL) figure as this safety excess is calculated into the strength of the equipment, not the size of the load. We are saying in essence that the load is 200kg therefore the equipment must be able to support more than that, with the exact size of the excess (201kg, 250kg or 300kg) being decided by regulations and possibly varying quite a bit.

Outside the UK a lot of texts define a bodyweight at 100kg, hence option (b) above. Within the EN standards a standard bodyweight is 70kg, hence option (a). In reality the majority of active cavers are less than 100kg and modern stretchers and splinting equipment weigh very little compared to the sort of equipment used 10 years ago. For example the SKED stretcher comes in at a little under 9kg, whereas some stiff-frame Neil Robinson stretchers were over 30kg when moist!)

The 200kg figure is also the accepted limit for many manufacturer tests of rescue equipment. The British Columbia Council of Technical Rescue (BCCTR) have three figures; 80kg for a 'single load', 200kg for a 'rescue load' and 280kg for a 'three-man load'. In the UK it is not accepted practice to support more than two persons on one rope and so we do not include this higher figure. US teams that routinely use triple loading must use the techniques and mathematics of this book with care. Of course the team could rig up a hauling system and connect it to a rock the size of a small bungalow, but that rapidly ceases to be a run-of-the-mill ropework problem

The peak load on any single anchor point is 12kN

This is based on values originally used by the BCCTR, which fixed a peak load limit at 15kN. Subsequent work in the USA and UK has shown that for older anchors and karabiners this may be too high, so a value of 12kN is used in this book. Many manufacturer tests for belay devices now use this value. Note that the term 'anchor point' includes the rigging route to that anchor as well. In many cases of high loading the point of failure is the karabiner or sling rather than the anchor itself, and this is especially true with modern resin hangers. Research by the USAF in the post-war years showed that the limits of survivability for upright seated adults (i.e. in aircraft ejector seats) was 12kN [Burton, 1985; Webb, 1964]. We apply the same limit to a casualty secured into a rigid stretcher that is supported either vertically or horizontally. This does not account for any exacerbation of injuries, which of course can be fatal even at very low forces. Casualties with spinal fractures, even immobilised, can suffer critical misalignment of the cervical column in a vertical fall of only 1kN. As a point of comparison a limit of injury for a caver falling in a sit-harness alone is between 4kN and 6kN.

The maximum expected fall factor is one-third

In caving it is rare to climb above the anchors, so fall factors are limited to less than 1.0 except in moments of madness. In the specific area of rescue hauling and belaying the systems are designed to prevent all but small falls, normally by the use of backup lines and redundant anchors. Small falls resulting from failure of pulleys, anchors or karabiners can result in drops of a metre or so before redundant components take over. Our maximum FF of $^1/_3$ reflects this fact and is used by several other testing programmes. It must be noted that for fall factors in excess of 0.5 with a full 200kg load very few components will survive.

The maximum steady loading on any component is 8kN

This is based on the principle of a 200kg (2kN) load and a mechanical advantage through pulley systems and friction of 4:1. Although higher values are possible by more complex compound pulley systems, rigging in this book is designed to adhere to this limit.

There are some other minor points to define which we shall refer to in later chapters:

The average rescuer can hold or apply a 200N force with one hand

This is an average, based on a single gloved hand gripping 11mm SRT rope. Across sampled populations the grip strength varies from 20N to 400N.

The average rescuer can hold or apply a 400N force with two hands

Again an average, based on a standing braced position and a horizontal pull on 11mm SRT rope at waist height. When sitting down fully braced this figure does not change significantly as it is finger grip strength that matters most, though clearly if using artificial aids (clamps, knots etc.) the figures will be higher.

Reaction time to a failure or rope movement is 1 second

This assumes that the rescuer tending the equipment is alert and close enough that the time to travel to the equipment is negligible. In this time a free-falling object will travel 5 metres from a stationary start. I have been accused of assuming too much in placing an alert attendant next to the equipment, to which I reply this is a matter of training, not judgement! I would not envy the team leader who has to stand in front of an inquest and explain why a failure went unchecked for a few seconds simply because nobody was paying attention.

Finally we shall assume that in a UK cave rescue there is far more likelihood of a shortage of equipment than a shortage of rescuers. This allows us to err on the side of high manpower and low mechanical advantage, whereas self-rescue for sport cavers or mountain rescue rigging often has the limits defined by personnel rather than equipment.

We do of course have to keep things sensible, as British caves are not known for spacious galleries in which to arrange battalions of rescuers!

The Sudden Death Rule

When designing rigging systems for rescue we will often have to compromise on 'protocols' due to lack of equipment, difficult geology or time (in the event of some form of failure). One rule must persist through all short cuts, omissions and cheats – the infamous Sudden Death Rule:

The sudden death of any member of the team shall not cause a failure of the rigging system or place the life of others in danger

This means that if a rig requires constant attention from a team member (such as if you were to use an HMS hitch as the sole form of belay) then the removal of that member will cause the system to fail. It means that humans should not be 'built in' to the rigging system and that the equipment incorporated into your system must always fail safe if left unattended.

1d. Levels of response

This book concentrates on the ropework and rigging associated with such rescue. It does not include medical, management or search techniques (which are covered in other publications). It is also not a book on how to do 'personal caving', as that is territory well trodden by others. However before launching into the details of knots, pulleys and bolts it is important to define some ground rules for the overall structure of a rescue. We need to define the reasons for using ropework before we can establish the best way of doing it. What follows is a synopsis of a rescue and the parts thereof, based on the best current *suggestions* for methods and standards. I must stress that as of the time of writing there is no national policy within the UK for these methods (despite several attempts to generate one) and this is based on methods used in the USA, mainland Europe and Australasia. Here, it seems, progress has been more fruitful.

An underground rescue can be though of in five stages:

1. Rapid entry and search
2. Location of casualty
3. Exit route planning and rigging
4. Casualty recovery
5. De-rigging and team exit

The methods used in each stage vary dramatically in terms of ropework and working practices. Obviously stage 2 does not involve ropework per say, and stage 3 and 4 are combined in terms of rigging. What is of interest is the difference in techniques between stages 1 and 3.

Rapid entry and search is just that – small teams of rescuers must traverse the known (and unknown) cave system in a methodical manner whilst searching for casualties. The emphasis is on speed and coverage – a rapid search that misses out vital areas is useless, yet a very slow meticulous search can be just as detrimental to the victim's chances. For the rest of this book we shall assume some very important points about this part of the rescue:

- All 'search' ropework will use standard sport caving techniques
- Search ropework shall not be used for subsequent recovery

In other words a group of rescuers rigging a pitch during phase 1 will use normal single-rope methods. They will not use separate belay lines, redundant anchors, hauling systems or similar unless the situation would warrant such use in normal caving practice. The extra time taken to rig safety lines for search parties can seriously slow the search progress, and serves no practical benefit. Search parties will rig and de-rig pitches as the search progresses and so the workload is more than doubled if full 'rescue rigging' is used.

Some teams (and ardent legal fetishists within them) insist that even during search rescuers must use the full redundancy of 'industrial' rigging where everything has a backup. I believe this is counterproductive in terms of time and safety and instead rely on the 'acceptable risk in the real world' idiom. Cave rescue teams work to the prime directive that the safety of rescuers is more important than that of the casualty, therefore some imply that this means industrial methods of redundancy must be used. I argue that if we assume all rescue team members are skilled cavers (which they must be) then their personal safety when operating alone should remain with them. If a rescuer is competent at SRT there is no significant risk benefit in making them use redundant rigging where it is not absolutely necessary.

Decisions on which aspects of sport caving to adopt are a matter for the team themselves. Some teams forbid the use of electron ladders (with lifelines), others allow them. Often it is an issue of the local terrain and likely routes. It is true that a ladder is more rapid to use and deploy on a 2m entrance pitch, but the effort in getting ladders 500m underground to rig a 40m pitch is prohibitive. There is also an issue of personal SRT kits used by rescuers, which I will discuss in a later chapter.

If a team adopts the first rule of this phase, then the second rule must follow. Pitches, anchors and lines rigged for search using 'sport' methods are inadequate for full rescue loads and MUST be replaced should the recovery phase use that route. Often anchors (in the form of bolts or natural formations) can be re-used but it must be a policy to completely remove the search rigging and fully replace it, every time. Trying to modify an in-situ rig to upgrade it is a recipe for disaster, especially if more than one rescuer is working on it. Parts get swapped twice, parts get left behind.

During the *recovery phase* the rigging must be rated to take the full rescue loads of hauling. Even if a casualty is 'walking wounded' and being assisted to climb out himself or herself, it is important for legal reasons to use the same methods as for a 'dead weight' load. Teaching a rescuer two methods of rigging for different levels of casualty assistance can lead to disaster if the injuries suddenly get worse en route. You may be left with a final pitch rigged for 'walking wounded' and find that at the bottom arrives a stretcher full of unconscious caver. The rigging methods presented in this book relate to this recovery phase.

The golden rule for the recovery phase is simple – for each scenario you should have a choice of alternative rigging methods to choose from, but based on the exact details of the site and the gear available there must always be a clear best option, which should them always be used. It is pointless to try and decide on a full standard rig for every kind of pitch, as inevitably the underground world will throw an obstacle in the way. However, you should standardise the *methods* as much as possible so that components like Z-rigs or belays are always the same.

De-rigging is often overlooked. With all rescues, underground and surface, the centre of activity and interest is always on the casualty. Looking from above the working frenzy flows outwards to the entrance with the casualty in the centre, leaving tired and often forgotten rescuers dotted about in the wake, tasked to 'clear things up'. It is not common in the UK (except for Yorkshire) for a rescue team to be sufficiently in demand that gear must be rapidly moved from one rescue to another, but it is very easy for kit to be abandoned underground if the people collecting it are not the ones who took it in. De-rigging is a management issue not a technical one, and teams are advised to set up a formal system of checklists at surface to ensure that what when in comes out. Post-rescue the cleaning and re-packing of kit is of vital importance and must not be tasked to the most fed-up looking caver on the team. The involvement of legal safety policies (CE marking and PPE regulations) mean that 'maintenance and checking' of equipment is now a legal requirement, not just a sensible thing to do.

As is the nature of rescue there is an important issue of conditions. I have created the framework of response above being careful to include words like 'suitable', as it is often the case that a rescue team has to enter, search and recover from a cave in conditions that would prevent normal 'sport' access. High water is the most common and obvious issue but there are of course others (gas or oxygen problems, unstable rock falls, pollution…) and the methods must adapt to reflect this. The search phase and the use of sport caving techniques must of course be changed if those techniques do not offer adequate protection for the rescuers. If a team must descend a pitch in extremely high water then extra backup lines, stronger anchors, additional bolts and even the odd sandbag may be vital. There is a fine line between rapid response and creating an additional casualty, and that line is drawn by experience alone.

So, now we have our rescue scenario. The team searches the cave and locates the casualty, a plan is hatched to bring them out and gear is brought forward. From this point onwards in the cave ropework must be entirely rescue-rated, and from this point onwards in print I aim to show you how.

1e. Medical influences on rescue ropework

As I have made the point of stating (mostly for the benefit of the lawyers reading this), *Life on a line* is not a medical text. Having said that, being written by a medical author I cannot let the subject go unmentioned. Apologies for the brief divergence…

Currently the standard medical training given to cave rescue teams is delivered under the Mountain Rescue Council's 'Casualty Care' programme, and training manuals are available from the MRC. I assume throughout this book that the casualty is being attended by one or more team members who have the skill and training to deal not only with the extant medical condition of their patient, but also to advise riggers on the transportation methods best suited to that condition. Difficulty arises in the underground environment when the riggers reply (as they often will) that the required method of transport is simply impossible to achieve. This is reflected by the current 2-page section in the MRC Casualty Care training manual on cave rescue, which (without wishing to be prejudicial) makes the point that cave rescue is difficult, very difficult, and beyond the scope of the book. After having watched cave rescue team members undertaking their medical training it is clear that surface rescue medicine needs significant overhaul to apply underground, where the book-form answer of 'now evacuate the casualty immediately, preferably using helicopter assistance' led to looks of despair.

Leaving this aside the important points from my personal crusade are as follows:

1. The medical condition of the casualty may *require* a certain type of rigging (such as a horizontal stretcher haul or inability to self-assist) but the physical nature of the cave has the last word, so medics must sometimes expect to have to go with what the riggers can achieve and deal with the medical implications appropriately.
2. By far the best (and most usual) option is for any casualty whose medical condition permits to exit the system under his own steam (self-evacuation) or to assist in his rescue (self-assist) by for example leaving his arms free from the stretcher to hold onto rigging and passage walls. Teams must however plan for the possibility that the ability of the casualty to self-assist or self-evacuate may vanish before they reach the entrance. Being told a casualty is 'making his own way out' from –100m is not an excuse for putting the stretcher back in the stores. An injured, cold and stressed casualty is more likely than ever to suffer another accident on the way out, so prepare for it.
3. There is always a situation where the rules no longer apply.

Point 3 is remarkably easy to reach underground, compared to surface rescue. Without wishing to be rude, a surface incident can *always* be engineered to suit the injuries of the casualty. It may result in long delays, but with shelters, helicopters and no physical constraints on their 3-D movement, things are far from impossible. Underground it is almost trivial to create a situation that breaks every protocol in the book. Take for example a casualty with an unstable spinal fracture on the far side of a tortuous wet flat-out crawl with a few bends. According to the medics the casualty must be immobilised on a stretcher and cannot be allowed to twist under any circumstances. According to the cave, they have a crawl to negotiate. The moral is simple – rescue from confined spaces requires most of the rules to be made up on the spot. This book aims to give you ideas from which to make those rules, not the rules themselves. You'd only have to break them.

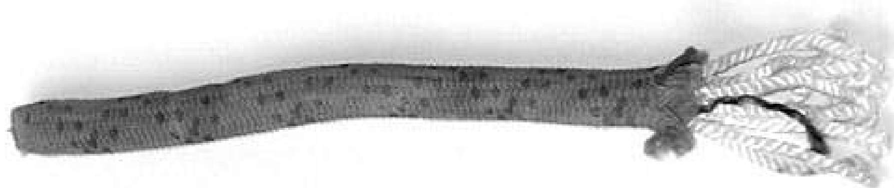
2. Rope

In a book on ropework a chapter entitled ‘Rope’ may seem a little obvious, but this is probably one of the most complex and contentious parts of this work. When discussing the use of rope in rescue and the techniques, knots and devices applied to it; there is of course an advantage in knowing a fair amount of the properties and abilities of the rope itself. The difficulty for many teaching ropework is that this section tends to be written off as a misplaced appendix, full of chemistry and physics and not worth reading unless there is a particularly boring night on TV. As a result riggers can learn knots without a real understanding of *why* they are good or bad, and when pushed into making decisions ‘in the field’ they can be left without a clue. Taking any other trade such a lack of insight would be amazing. Carpenters who did not understand the way wood works under stress or when wet… builders who had no idea why they put aggregate into concrete… not very common.

For me, parts of this chapter were trivial to write and parts almost impossible. Manufacturers publish almost every property and specification they can think of for new ropes in an effort to sound better than the crowd. Standards for ropes are rigid and publicly available. The problem arises as soon as the rope is taken underground or put into a storeroom. No manufacturer will provide data on how an *old* rope should behave, and there are no recognised standards, tests or measurements that have been applied to more than a handful of samples. As every piece of rope that a team uses is effectively old rope, understanding the way it behaves is akin to choosing a new employee based on their first school photograph.

Throughout this chapter we have illustrated where needed to show the point under discussion. However the best and simplest way to understand the construction of a rope is to take one apart. I strongly recommend that all team riggers learning the trade start by taking a knife to some old samples of rope and (to analogise with my medical colleagues) learn by dissection.

2a. Construction and materials



All modern ropes used for rescue underground are kernmantel construction, a technique developed by Edelrid in 1953. It is only allowed by the use of polymers as it requires the ability to produce single strands of yarn at any length. Natural fibres are limited in length and are therefore only suitable for ‘laid’ construction. The use of natural fibre or short-yarn laid ropes in critical rescue applications and for PPE is effectively outlawed in the UK and such ropes should never appear in a team kit, even for tying up a bundle of logs.

If it is there, someone one day may make a sling out of it. I hate to have to say, however, that there remains a large quantity of laid rope (mostly old pre-stressed terylene) in active use by surface rescue teams and statutory agencies, more on that later.

Kernmantel rope is formed from a bundle of effectively endless polymer fibres are twisted or plaited together to create a loose core (‘kern’) that is strong but very susceptible to abrasion. It is then surrounded by a woven sheath (‘mantle’), which protects the core from damage and holds it together into a secure functional object. For trivia fans, the core must constitute a minimum of 50% of the mass of the rope before it can be called ‘kernmantel’. The interaction of the core and sheath under load is complex and not completely understood even today, but it is clear that the resulting rope is about as close to the ideal as you can get. Ultra-modern polymers and weaving techniques can create ropes with better strength, less weight or long life, but nobody has worked out a better overall design.

The core manufacturing processes are slightly different for semi-static and dynamic ropes, and it is this difference that gives dynamic ropes the ability to stretch. *Both* types of rope are formed from a parallel bundle of twisted yarns. The number of bundles and their layout depends on the manufacturer. The idea of using such a ‘bundle of twists’ is that under tension there is no net torque on the rope as there is for a laid construction. A climber suspended on the rope therefore will not spin around as the rope stretches, vital for SRT. Naturally, these core strands have a limited amount of elasticity, partially due to their ability to straighten under load but mostly due to the inherent elasticity of the polymer itself. This is the effect that semi-static ropes rely on, so to get more elasticity for a dynamic rope the core yarns are heat-treated to make them shrink slightly. Under tension they therefore have a larger elasticity as required. The point of this is that if it were not for marker yarns and coloured sheaths it would be almost impossible for someone in the field with a knife to tell what type of rope he’s got. In performance, however, the differences become very apparent. Despite ‘physically’ being the same, when you apply semi-static and dynamic ropes to equipment, knots, sharp edges and fall factors the slight difference in elasticity results in often extreme differences in behaviour. Obviously the maximal example is that a dynamic rope taking a fall of FF2.0 may well survive. Semi-static rope will not.

The sheath of all kernmantel rope is a plaited construction, again designed to impart no net torque under load. A plaited tube is also useful in that under tension it contracts, squeezing the core yarns together and increasing the friction between them. This modifies the elasticity to reduce the shock loading. The sheath provides a significant fraction of the overall strength of the rope as well as protecting the core from dirt and abrasion. Since the sheath is the only surface to be in contact with SRT devices or knots, a lot of design goes into choosing the right weave size and yarn tension.

At this point I would like to *again* emphasise a point related to the use of braided terylene static rope, which unfortunately is still in common use by surface rescue teams, the Fire Brigade and other agencies. Irrespective of the age of the rope and the true strength it may retain, there is a simple and unavoidable argument why braided rope should never be included in cave rescue rigging, namely that of compatibility. Modern SRT devices (ascenders, descenders, belay devices and so on) are specifically designed and intended for use on kernmantel rope meeting the requirements of EN1891 or EN596. Using such devices (for example an autolock descender) on braided rope will lead to erratic and often dangerous behaviour. Apart from the fact that the manufacturer will absolve all blame should the issue reach an inquest, you have created a system whose performance you do not understand. Trying to lower off a critically-injured casualty is not the time to find that your descender has jammed because a braided rope has been used. Hopefully underground rescue teams will not have this dilemma when operating alone, however it is something to watch out for when working alongside surface agencies.

2a1. Materials used for kernmantel ropes

Modern kernmantel ropes are usually based on nylon, polyester or polypropylene, though specialist rescue ropes designed for high temperature may use different materials. Webbing (as used for slings and in harnesses) is either produced from the same rope-making polymers or from high-strength polymers such as aramids or HMPE. The performance of rope or webbing is of course dependent on the construction methods. Here we cover the materials used and the way they can influence the rope. I should stress at this point that whilst what follows may at times seem more like an organic chemistry lecture than a cave rescue text, it is important to understand your tools. Skim through and pick up the salient points by all means, but don't avoid it completely.

Firstly, it must be remembered that the drawn and woven strands of polymer within a modern rope or webbing cannot be expected to perform exactly the same as a solid block of the base polymer. Issues such as melting point are the same, but mechanical effects such as flexibility, ductility and elastic modulus can vary a great deal. 90% of what we shall cover in terms of the performance of ropes under tension is related to the macroscopic world of the weave and of friction between strands rather than the microscopic world of chemical bonds and polymers. For rescue teams what matters is how the rope performs mechanically, what temperature range it can be used under and how it alters with age. The rest is not perhaps of direct interest but I include as much as possible in this chapter simply because so much is still uncertain. As nobody really knows how rope performance changes over time I decided it was worthwhile to put a fair amount of background into this chapter, just in case someone reading it can spot the patterns that have eluded us to date.

Rope is produced from polymers, meaning that when heated they first go soft and ductile, then melt, then eventually most will burn. Clearly for rigging purposes the point of burn is not of much interest if there is a lower temperature (the softening point or T_s) where the rope will lose all interest in holding a load. The melting temperature is of course the point where the polymer becomes liquid, and is of interest in issues such as friction, or a hot descender, causing *surface* melting of the sheath. The softening point is relevant to elevated-temperature rescue (such as with the Fire services) but also whenever a rope is left in contact with something hot such as a pulley (or that descender again). All ropes and webbing supplied by the manufacturer under European PPE regulations should have a working temperature range stated in the literature.

As well as thermal effects, all polymers can be affected chemically by other compounds. Usually a polymer is sensitive to acids, alkalis or organic solvents, in whatever combination. Often ropemakers select the materials specifically to provide chemical protection in equal importance to strength.

I will summarise the main rope-making polymers below, or at least the important and relevant points about them…

Nylon

Nylon-6,6 is the most common rope-making plastic. It is a polyamide and some manufacturers (e.g. Mammut) label their ropes as 'polyamid'. It softens at T_s=230°C and is stable up to working temperatures of 100°C. Nylon-6,6 is attacked by strong acids but is resistant to alkalis. It is also resistant to most common organic solvents but can be dissolved in formic acid and phenol (both equally horrible to almost everything else). It is quite susceptible to damage from UV radiation, and when completely saturated can absorb up to 7% water. It has quite a high stretch but the issues of age and performance are complex. With a high bulk density it sinks in water. Nylon ropes are discussed in greater detail later in this chapter.

Polypropylene

This softens at T_s=165°C. It is resistant to both acids and alkalis, except oxidising acids. It is insoluble in most common organic solvents below 80°C. As for nylon it is quite susceptible to damage from UV radiation, but when completely saturated can only absorb up to 0.03% water. This means that when wet, polypropylene yarn retains more of the 'dry' strength than a similar sample of nylon. The bulk density is lower so it can float on water. It is used for the sheath material of some static ropes such as the New England KM2.

Dyneema/Spectra

Both are trade names for high-modulus polyethylene (HMPE), also known as ultra-high-molecular-weight polyethylene (UHMWPE). 'Dyneema' is the trade name used by DSM High Performance Fibres of the Netherlands, and 'Spectra' is used by Allied Signal Inc. (USA). Hoechst Celanise also makes HMPE yarn under the name 'Certran', and there are probably others. For brevity I shall call this material HMPE from here onwards.

HMPE is one of a relatively new group of 'polymer metal substitutes' whose yarns have similar properties to steel wire of the same diameter. The most important properties in terms of climbing or rigging equipment are the static strength and elongation. HMPE, weight-for-weight, is about 10 times stronger than steel wire and this has led to it's use in many applications where steel tethers were the norm, such as on climbing 'nuts' or in winching. It has a melting point of around 135°C, is resistant to acids and alkalis and shows very little deterioration under UV exposure. HMPE does not absorb water microscopically, nor does it lose any strength when wet. The very low density means it can float on water so it has seen application in marine rescue systems.

HMPE is used in webbing and accessory cord but has limited application in true rope, and the strength of the polymer is the main reason. Under tension HMPE has an incredibly low modulus of elasticity (stretch), and even at 50% of the breaking load a sample of HMPE webbing will probably only stretch by 2%. This low-stretch is ideal for industrial applications such as winching and lifting where 'bounce' is not wanted, but for climbing or caving the results of a fall onto HMPE can be catastrophic. As there is effectively zero stretch in the system, the peak forces on the anchors, karabiners and the climber's body can be massive. If the metalwork in the system survives the forces, the climber will almost certainly be killed by the acceleration forces. This is one example where a material is almost too good!

HMPE does however suffer from a process called 'creep', where the fibres very gradually elongate under a sustained load. In fact the elasticity of HMPE is very complex – sufficient to warrant a little diversion from the main flow of text…

Elongation in HMPE (based on research at the Eindhoven Institute of Technology for DSM)

There are four processes at work when a new sample of HMPE is put into load:

1. Constructional elongation: An initial and irreversible stretch while the weave and lay of the yarn settles into position. Occurs only on the first loading and amounts to about 2 – 6 % by length.
2. Elastic deformation: the 'normal' elastic stretch of the yarn under load. Occurs immediately the load is applied, is fully reversible and amounts to typically 0.2 to 1% under 50% of the breaking load.
3. Delayed deformation: A slow and delayed stretch under load, usually identical to the elastic deformation and also reversible. Occurs on every loading.
4. Creep: This is a permanent and irreversible stretch, though it is very slow so only occurs in long-term loading. It is accelerated by high loads and high temperatures and there is a variable 'threshold' load below which creep does not occur. It is only really relevant to winching and lifting applications.

HMPE webbing for slings and tethers is ideal for rescue work as it has good chemical resistance, very high strength/size ratio and can take a fair amount of punishment underground. However, it is vital to avoid using HMPE in any rigging situation where a shock load would be transmitted through it and it alone. The temptation to use an HMPE sling as a super-strong cowstail could result in a falling caver's last sight being pieces of broken karabiner flying past his head… It is a useful (though limited) analogy to consider any HMPE equipment as if it were made of steel cable.

One drawback of HMPE is that it is very slippery. This helps to reduce friction against anchors or karabiners, but means that it is extremely hard to tie a good knot in the material. Under sustained tension the webbing or cord can very slowly slide through a knot, eventually coming apart. This process has a number of names (some vulgar) though I prefer the US term 'slither'. It is very important when installing fixed anchors using HMPE that the tails of all knots are long enough to resist slither. Ideally, mark the position of each tail on the standing part so it can be easily checked. Never use a knotted HMPE sling on any long-term permanent rig where it cannot be seen and inspected. Sewn slings are obviously not subject to slither.

Aramids

The aramid family of polymers includes Kevlar (a trademark of Dupont), Technora (Teijin) and Twaron (Azko). Famous for use in ballistic protection, aramid fibre has a very high strength and abrasion resistance, as does HMPE. However when bent against each other, aramid fibres have a tendency to cut each other. They are also less flexible than HMPE for a given diameter. Aramid can almost always be recognised by the distinctive yellow/beige colouring of the base polymer as it is impossible to dye. Aramids have a slippery surface similar to HMPE, so can suffer from slither at knots. There is no published evidence of creep, but given the limited application of aramids in modern climbing and caving equipment it is probably safe to assume the majority of the time you will never encounter it (except in your bombproof abseiling gloves!) It doesn't have a true 'melting temperature' but becomes charred at ~450°C. It is very dense so sinks in water.

Vectran

This is a trade name for liquid crystal aromatic polyester (LCAP), recently introduced by Hoechst Celanise. It is visually similar to aramid but not quite as yellow. It melts at 330°C and is almost as dense as aramid so sinks in water. There is limited data available on the real-world performance of Vectran at this stage, but it is safe to assume a performance similar to aramid-yarn equipment of the same design. LCAP allegedly reduces the self-cutting effects that cause problems for aramid-based equipment though long-term performance and ageing data is still awaited.

2a2. Common chemicals and their effects on polymers

Here is a selection of common chemicals likely to be found in or around ropes, usually in storage or transport. The effects of **rust** and **water** are discussed elsewhere.

We have marked the effects on strength using the following codes:

R resistant, no strength loss
SR semi-resistant, only minor strength loss
D damaging – can cause strength losses of significance to subsequent use
VD very damaging – can cause severe loss of strength
? effects unknown or published data contradictory

Of course any exposure of critical equipment to a damaging chemical should be grounds for destruction of that equipment. Often the damaging effects are long-term, but equally a thorough washing of the offending item will not restore the strength already lost.

	Nylon-6,6	Polypropylene	HMPE	Aramid
Petroleum fuel[+]	R	R	R	R
Diesel fuel[+]	R	R	R	R
Lubricant (WD40)	R	R	R	R
Sulphuric acid (caving battery strength)	D	SR	SR	D
Alkalis	SR	SR	SR	R
Urine[++]	D	D	R	R
Blood	SR	SR	R	R
DEET (insect repellant)	R	R	R	R
Ozone	SR	?	?	?
UV light (sunlight)	SR	SR	R	D

+ Although tests conducted by Black Diamond in the USA show that soaking of climbing ropes in automotive fuel does not significantly weaken them when subsequently drop-tested, it is extremely bad practice to store ropes in the vicinity of any hydrocarbon fuels or solvents. Apart from anything else you will end up with a very flammable coil of rope…

++ Tests, again by Black Diamond, show that a urine-soaked nylon rope can lose up to 50% of the original strength in subsequent drop tests.

2b. Marking

Almost all manufacturers also use the sheath as a means of identification, introducing a pattern of coloured yarns to show rope type and diameter. Whilst there are a few exceptions, in general semi-static rope has a sheath base colour of white or black (with black being produced for tactical and military users) whereas dynamic rope is intentionally colourful and never plain white or black. This is deliberate to avoid confusion.

There are no rules on the patterns used to denote diameter for rope, which is a shame and may well be regulated upon in the future. Now, however, it is a matter of knowing who made the rope before you can be sure of how to read the markings. Under the current EU standards regulations every compliant rope must contain a marker tape – a thin strand of plastic inside the core, which is coloured to indicate the year of manufacture. There is however no agreed standard on the colour coding, each manufacturer uses a different set. Many manufacturers print their name and the rope type on the tape, so it is possible to go back and obtain the colour coding once the maker is known.

There can be problems if you encounter 'tactical' rope whilst in the course of your work. By design this is always totally black and identifying diameter or even the maker is impossible once the end tags have been removed. Tactical rope is often designed specifically for high-speed descent at the cost of other aspects of performance, and so should not form part of a regular team kit unless operational needs demand it. Within the UK there are no tactical duties imposed on cave rescue teams, though rarely they may encounter such ropes when working or training alongside police or military teams. Given the choice in that situation, stick to your own normal ropes.

Dynamic ropes are far worse in that there is hardly any logic to patterns, apart from an obvious intention to make the rope look nice. You must rely on the identifying marker tape within the core to find out the manufacturer and age, then work back from there.

2c. Flame-testing rope fibres

This section may seem superfluous to some readers but I wanted to include it for completeness, as it is not at all easy to find this information anywhere else. If you have a sample of rope fibre and you cannot identify the polymer by any other means, then there are some simple tests you can do using a bucket of water and a gas stove. Two points are important:

1. This is a test for fibres, not ropes. If you try the test on a complete rope where the core and sheath are made of different polymers, you will get useless results!
2. The flame needs to be clean and colourless, so a domestic gas flame is suitable but a candle, match or other ‘yellow’ flame is not.

The first test is to see if the fibres float, then hold each fibre in the flame. While it is in the flame observe the way it reacts and burns, then remove it from the flame and see what it does. Finally, blow it out, leave it to cool and examine the fibre.

Test	Nylon 6 and 6,6	Polyester	Polypropylene	Polyethylene
Floats?	No	No	Yes	yes
In the flame:	Melts & burns White smoke Yellowish liquid drops	Melts & burns Black smoke Dirty drops	Shrinks & burns Dirty drops	Shrinks, curls & burns
Out of flame:	Stops burning Melted bead can be stretched into a fine thread	Stops burning Melted bead can be stretched into a fine thread	Continues to burn rapidly. Melted material can be stretched into a fine thread	Continues to burn slowly. Burnt material cannot be stretched into a fine thread.
Afterwards:	Hard yellow bead	Hard black bead	Hard brown/yellow bead	Waxy soft residue
Smoke smell	Fishy	Oily and sweet	Waxy, like asphalt	Paraffin wax

2d. Choice of ropes for rescue

Based on the requirements for industrial rope access in the UK, it is becoming the norm for rescue team ropes to be 11mm diameter minimum. Rescue obviously places greater loads on ropes than either sport caving or rock climbing, and these loads are often applied in far from ideal conditions (wet or muddy). Basic static and dynamic ropes are available in diameters from 9mm to 13mm, though 9mm-11mm is the common range in most stockists. Assuming that during a rescue there is not a significant shortage of manpower or transportation then the weight per metre of rope is not a factor in the decision. Similarly although a large coil of 13mm rope requires a much larger bag than a coil of 9mm rope, in the UK the underground pitches rarely exceed 75m. Large pitches (100m+) are exclusively surface shafts (mineshafts, etc.) where the physical size of a rope coil is irrelevant.

There is a clear argument for using the largest possible rope diameter on the grounds that it is (a) stronger and (b) less stretchy under small loads. If this were the sole issue then all rescue teams would be using 13mm ropes, however caving equipment (ascenders, pulleys, descenders) are often designed for a limited range of rope sizes. Examples include:

Equipment	Min diameter (mm)	Max diameter (mm)
Petzl Stop	9	12
Petzl Shunt+	8	11
Petzl ascenders (Basic, Ascension, Croll)	8	13
Petzl Grigri+	10	11
All Petzl pulleys	-	13
Kong Indy descender	9	13
DMM Double Stop	8	13
Generic 'rack' descender	8	12
Petzl I'D descender++	10	13
Petzl Rescuecender	9	13

+ The Shunt and Grigri are only designed for use with dynamic rope
++ The I'D is available in two sizes, for 10-11.5mm ropes or for 11.5-13mm.

Given that the Shunt and Grigri are, in later chapters, to be extolled as a useful part of rescue rigging it seems that 11mm is a sensible compromise point. It also makes sense in terms of cost, as 12 or 13mm rope is significantly more expensive due to low demand. A proposed policy from the UK Rope Rescue Association makes 11mm static and dynamic rope standard, and I agree with this. Finally during the search phase of a rescue, team members will be using 'team' ropes under normal caving conditions as they search. It is therefore important that the ropes work with all normal personal SRT equipment. Although the Stop is rated for 12mm ropes in the majority of cases a normal weight caver will find it very difficult to descend on a 12mm rope due to high friction, so:

Rescue ropes should all be 11mm diameter

Of particular importance in rescue teams is that all ropes should be identical diameter. Mixing 10, 10.5 and 11mm ropes is unnecessary and bad practice. Team members may not be 100% familiar with the intricacies of marking threads in rope and must be able to know without checking that a rope is of the normal strength. This is especially true of dynamic ropes, where there is no regular method of marking the diameter using marker threads. Thinner ropes for specific applications (such as 8mm cord) should be of an obvious and contrasting colour to any load-bearing ropes. Of course it goes without saying that each end of each rope must be permanently marked with length, diameter and a serial number or purchase date. The later chapter on rope testing assumes that there is a procedure within each team for a rope to be traced from purchase to disposal. Many teams can trace ropes on a callout basis – most mountain rescue teams hold logbooks for every rope that can trace every time it is used, how many falls it has taken and where it came from. As rope longevity is such an unknown area collection of the most data possible can only benefit those trying to make sense of it.

The choice between manufacturers is not an issue for this book. All recognised manufacturers produce ropes that exceed the current standards. Some include water repellent, some make ropes extra-flexible, and some make ropes in nice colours. Above all that, most UK rescue teams are funding-limited and so the best type of rope is the one that can be bought for the least money. It is however worth considering the purchase of some coloured static ropes for hauling systems, as it has been proved by the CRO and others that operating dual-rope systems is vastly easier if the ropes are different colours. Anyone at any point in the process can understand what 'take in on the green line' means, but 'pay out line one' is as confusing as watching snooker in black-and-white unless you have put numbered tags at each end.

2e. Transport and storage of rope

The underground environment is extremely harsh on equipment of all types and rope in particular. Grit, mud, sharp rocks, constant damp and rough handling take a toll on ropes and it is rare to find any other vertical sport which exposes vital equipment to such destructive conditions. Cavers therefore have an added impetus to minimise the damage through careful transport, washing and storage. This section does not attempt to describe the rope care used by sport cavers, as all active SRT-users should be looking after their ropes as a matter of course.

Rescue teams have a few significant differences in the way their rope stocks are used, which influence the way it is cared for:

- Teams require rapid response to callouts, so ropes tend to be bagged ready for use at all times.
- Many teams have specialist ropes (static and dynamic) that may not be used for several months or years.
- Almost all teams have bases that can be made ideal for rope storage.

In contrast the stereotypical image of the UK sport caver is someone with a few well-used ropes that probably live hanging on a hook in a garage, get washed and inspected rarely and replaced only when funds allow or the sheath becomes frightening.

For optimum life, rope should be stored in cool (not freezing) dark and dry conditions, and be neither coiled nor tightly packed into a bag. As we have said in the rope construction section, the core of SRT rope is laid in parallel bundles to prevent the caver spinning in a free-hang load. This makes the rope susceptible to kinking if it is coiled into a loop and then paid out without removing the loops. SRT rope in a coil behaves like hosepipe or electrical cable and must be uncoiled in the same manner as it was coiled, or the core can be forced into a twist. This twisting is unstable in an opposing lay, and will lead to a sudden 'kink' appearing. A caver abseiling towards a rebelay can find a massive collection of twisted rope just above the anchor.

This kinking problem clearly prevents ropes being stored in normal 'overhand' coils and is the reason for using a random pattern when stuffing rope into tackle bags. Rescue ropes, being thicker, take up more volume per metre when packed in bags and the need for small bags and long ropes mean that many rescue team rope lockers contain tackle bags packed so tightly they can be driven over without changing shape. This is in many ways worse than storage in a coil. A very tight stuffing pattern is in effect a hugely complex knot, and as we shall discuss the rope can be locally weakened when left in a fixed knot for extended periods. The effect is small, but as with all rope care it is the sum of many small things that leads to failure.

One solution is obvious – do not pack bags tightly. The problem is that for a useful length of 11mm SRT rope (say 50m) you need a large bag to retain a loose pack. Even a large size bag can become a tight fit for stiffer 11mm rope. Whilst there is no excuse for using a bag that is clearly too small, there is a limit to the size and number of bags a team wishes to have to carry. Resigning ourselves to reasonably 'snug' packing then it is vital that the ropes get removed and repacked regularly, to move the loops and twists around. Specialist ropes that are rarely used or which are not transported underground (such as long ropes for deep surface shafts) are better stored on a reel. They must be paid out by revolving the reel rather than slipping turns off one end, but for a long surface pitch having a reel-loaded rope is a great benefit. Some teams keep a full 200m reel of rope and an A-frame stand for this purpose. Fitting a handle to the reel allows it to be recoiled after use far faster than stuffing it into a sack. This is not a valid option underground, both for reasons of rope protection and size.

New ropes, or those which for some reason you do not keep in tackle bags, should be coiled mountaineering-style, laying turns back and forth across your palm and then gathering the coil together with a few turns of the tail end. This style of coiling is designed specifically to prevent any twists being introduced. Creating rope chains using overhand knots is extremely bad practice and should never be done by rescue teams for long-term storage.

Storing ropes in the team depot is relatively simple to get right. The chosen place must be dark (to protect against UV damage) and cool. It must not freeze so frost protection is needed for unheated buildings. A dry atmosphere is vital to prevent mould and dry rot. Whilst not directly affecting polymer ropes, damp air will lead to rust and will prevent equipment from fully drying out after use. The store should therefore have good ventilation, especially if your team has a habit of replacing kit into storage that is still wet. Ropes pre-packed in bags can be hung from hooks or stored on shelves, as there is no direct contact between the rope and the hanger. Exposed coils should be hung from plastic posts, never metal hooks. They should be left hanging in free air as much as possible to maximise airflow and aid drying. Many teams have made racks based on short sections of horizontal plastic pipe. Older books suggest wooden pegs, but these can pick up rot when in prolonged contact with wet ropes. Whilst rot cannot in itself cause damage to the synthetic fibres of modern ropes it leaves the store, and equipment, with an unprofessional odour of neglect. When placed in a stretcher and slung into mid-air the last thing (possibly) the patient wishes to smell is mildew!

In summary then,

1. Dedicated surface ropes may be better on reels for ease of deployment.
2. All underground ropes must be packed in bags for protection, and response times mean that these will be pre-packed in the stores.
3. Always use as large a bag as possible to reduce tight packing stresses.
4. Remove every pre-packed rope at least once every three months, stretch it out and repack it.*
5. The rescue store should be dark, cool, dry and protected from frost.
6. Ropes not pre-packed in bags should be hung in mountaineering coils from plastic pegs.

* Some teams reverse the direction of a rope after each repack, though once a new rope has been bedded in there is no great gain in this procedure.

2e1. Washing and drying

Beyond the issues of biohazards as detailed in chapter 13, ropes clearly need washing after use. Any surface dirt left on a rope will damage metal equipment and wear out descenders, plus can abrade the sheath. Engrained dirt can have a small weakening effect on the core yarns over time. Washing rescue ropes is often the task that every team member avoids, especially if there are many hundreds of metres of rope to deal with. All teams should have a ropewashing rig either at their depot or available locally. There are many designs for ropewashers, but all rely on the idea of forcing the rope between stiff brushes whilst being sprayed with water. The simplest method is to mount stiff scrubbing brushes onto a pair of hinged planks that can be closed over the rope. Hosepipes aimed into the bristles wash out the grit as it is cleaned away. For cleaning large numbers of ropes something wall-mounted is far easier to operate, and use of an empty rope reel to take up the cleaned rope as it emerges makes it a 1-man operation. Ropes should be repeatedly pulled through the washer until they are visually clean, and a detailed sheath inspection should be made as the rope is finally repacked.

On a regular basis it is beneficial to wash each rope in a domestic washing machine to remove engrained grit. This should be on a cold (30°C max) setting. As the dirt on caving ropes is not grease-based there is *no benefit* in using detergent or washing powder, and so these should not be used if we follow the principle of exposing the rope to the least possible number of chemicals. Ropes can be spun dry but should never be dried in a tumble drier. To prevent knots when washing, ropes can either be chained or can be packed loosely into a mesh bag or pillowcase. One important point to note is that unless the rope is pre-washed on the team ropewasher, it can have a detrimental effect on the washing machine! One or two teams have their own dedicated kit washing machines, used for ropes, slings, tackle bags and anything else that will fit. Clearly they do not last very long, but often are old second-hand models. You may find a scrapped machine with a fault on the programmer or hot water/detergent system that will not matter for washing ropes in cold water.

2f. Breaking in new ropes

This is a point of major controversy in sport caving. Rope as supplied new from the factory has never been subject to full loading and is treated with numerous chemicals to protect the rope and assist in manufacture. When washed some of these chemicals are removed and the physical weave of the rope contracts, tightening the sheath around the core. Beyond that, the dynamic and static performance of a new rope is different to one which has been used a few times (but has not seen high fall factors). Some team riggers are ardent supporters of the ‘use it, wash it then store it’ philosophy, others argue that a rope on a fresh reel is at least guaranteed to be factory-perfect and why bother intentionally wearing it out. In rescue however, the decision is more clear-cut. Higher rescue loads place greater stresses on the rope and the initial shrinking during the wash process is vital to prevent large sheath slippage. In some ropes produced for extra flexibility the sheath as supplied factory-fresh is significantly looser than desired. When run through a descender on a rescue load or when subjected to a rescue fall factor the sheath can slip and bunch on the downstream side of the device to the extent that it jams within the cams or pulleys, leading to total failure.

Without trying to force a policy on an area where little work has been done, we can however make some points:

1) There is no scientific evidence to suggest that washing out impregnations has any good or bad effect on the rope, but if you are storing a new rope for some time before first issue (e.g. keeping a full reel for 6 months) it would make sense to leave it unwashed until it is put into service.
2) After the first wash/use/wash cycle nylon rope will shrink in length by approximately 10%, therefore length markers should either be revised after first wash or the rope washed and then cut to length.
3) Washing significantly alters the sheath/core grip, as does the first few uses. Rescue ropes must have low sheath slippage and so for this reason alone it is strongly recommended that all ropes are washed.

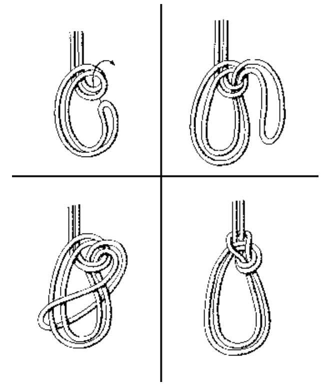
‘Breaking in’ also includes deliberate use of the ropes before issuing to the team stores. The idea is that for the first few descender runs the sheath is not fully bedded into the lay of the core, so with large loads there is a tendency for the sheath to slip. A 100m abseil on a new rope can result in a good 50cm of sheath being expelled from the end of the rope. Many US teams intentionally run a few full-length abseils on each new rope to bed in the sheath, washing the rope between cycles and always running in the same direction. After this process any extra sheath pushed off the end of the core is trimmed and resealed. This is not a policy of any widespread use in the UK, but as there is no evidence to suggest it causes any harm to the rope we cannot argue against it. The only critical point during these ‘use/wash/use’ cycles is that the ‘top’ end of the rope must be marked and that the descent always runs in the same direction.

2g. Time expiry and working life

The decision on when to retire a rope is the subject of chapter 12, as it is a complex issue. Books have been written on this subject alone, and we as a caving community are no closer to an answer. It is one of the few areas where the manufacturers have very little idea of what is going on either, so the decisions tend to be made on legal factors rather than scientific fact. Without wishing to summarise an entire section of my own book in one sentence it is clear that rope ages whether it is used or not, therefore storing rope for years is not the best policy. Many teams buy reel lengths of rope, bag up half of it and the reel then sits in a store until it is needed. With luck this would be for a deep shaft rescue a year or so later, but in all too many cases it is used to replace those same bagged ropes when they wear out. The result can be ropes that everyone thinks are ‘new’ but which have lost strength during their hibernation. If your team turns around working ropes within a year it may not be an issue, but if that reel sits in the store for 5 years before being cut up, you may be living on borrowed time.

Now that we have covered most of what we need to know about rope itself, though only a tiny fraction of what you *could* learn if the mood takes you, it is finally time to do something useful with it. Next stop – knots.

3. Knots



Naturally a book on ropework cannot avoid knots, though surprisingly few are needed for the general day-to-day rescue rigging I use in the later chapters. However the underground environment is not a place to run out of ideas, and there are a few other knots that are useful to remember for when equipment runs short, something fails or the situation you are presented with is like nothing before in history. Such is the norm in cave rescue.

Many of the excellent ropework books to precede this work are based on surface techniques where the knot is king. Given enough time and effort a knot can be constructed to do almost everything, assuming that the rope is well-behaved and you have the spare length, time and memory to work on it. The Ashley Book of Knots has over *three thousand* distinct forms of knot, hitch and bend. Underground the rigger must work rapidly and reliably, producing systems that everyone else can understand at a glance. Ropes are wet and mud-encrusted and do not show any inclination to knot easily. The last thing another rescuer wishes to find when he arrives at a rig is a knot that he cannot recognise or hope to untie. The prime notion of this chapter is therefore to select the minimum number of knots and provide the maximum amount of information on each. I cannot emphasise enough that every rigger in a team should be able to recognise, tie and untie every knot in this chapter without having to think about it. They may have to do this in far from ideal circumstances underground, and the need to pause and reflect on which rabbit does what to which tree is verging on negligence.

Surface rescue teams, and particularly those from the Armed Forces or Fire Services, may have several different 'acceptable knots' to my list. Having spent a great deal of time working with and training these groups, there is a simple decision process to follow when picking a knot. In order of importance:

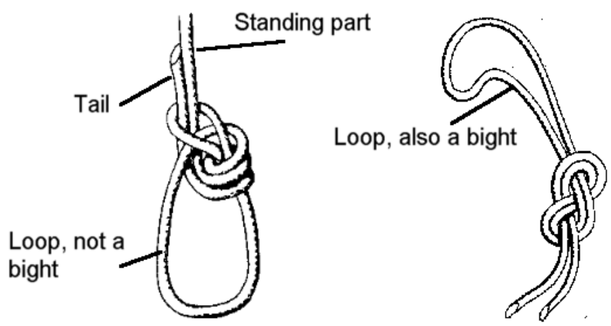
1. Is the knot suitable for the intended use?
2. Is it the strongest option?
3. Does untying or adjustment matter?
4. Will anyone else be able to understand what I've created?

The debate on item 1 is easy – the mechanisms of knots are well known, so picking a knot that can put a single loop in the middle of a taut rope is not difficult. Item 2 is, has been and always will be a subject for debate. As you read this, books, electronic email digests, websites and fights in the pub are going on about which knot is stronger than which. As an example of how complex it can get, almost all established sources accept that an overhand knot on the bight is the weakest possible way of making an end-rope loop. Tests have proved that knots like the figure 8, figure 9 and bowlines are all much stronger. That was fine, until a set of tests in the USA a few years ago, by an established and reputable rescue organisation, put an overhand on one end of a rope and various knots on the other. In pull-tests, the overhand was stronger. Nobody knows why, even the testing team. It just proves that a knot is a dynamic object on a mechanically complex structure, and predicting the exact percentage strength for every example anyone ever tied is as simple (and useful) as predicting the cracking of bathroom tiles in an earthquake.

Item 3 is important but should not compromise strength, after all you do carry a knife, don't you! Ease-of-release is important in certain selected situations (for example a rebelay on a pitch that you know will need to be untied during the rescue) but irrelevant in others (such as simple end-of-rope loop knots). Item 4 is a training issue not a technical demand – if you have a secret knot you love to use but the rest of your team have never seen it, they may not be able to see how to untie, adjust or load it. Beyond that, it is becoming important for legal reasons that another person checks rigging before it is used. If you are the only one who can understand the chaos you have created, the checker will have no idea if you've got it wrong.

3a. The elements of a knot

This sounds a strange section heading, but when talking about knots in a book it is vital to have a standard set of terms for the bits of rope and where they go. Photographs and graphics assist of course, but these terms are almost universal in the English-speaking world as they are taken from the nautical textbooks. There are many other terms for ropes and knotwork, from the familiar 'bitter end' to the obscure practice of 'choking the luff'. Whilst useful in quiz matches they do not help in learning and we shall stick to the basics:



- The standing part is the rope or ropes that emerge from a knot and are load-bearing. For example when tying a loop into the end of a rope, the main section of the rope is the standing part.
- The tail is the (usually) short rope that emerges from a knot and is not intended to be load-bearing. In many knots the tail can be load-bearing (such as a figure-8 loop) but in many it cannot (such as a bowline).
- A bight is a doubled-up section of rope. Knots tied 'on the bight' are tied using a doubled-up section of the rope, often to produce two loops from a knot that normally only produces one. Tying on the bight can also put a knot in the middle of a rope without needing access to the ends. The knot to the right above (a figure 8) is tied on a bight of rope.
- A loop is, obviously, an open loop created in a rope by the application of a knot. If it cannot change size by pulling on it, it is a fixed loop. If it can be made to change size, it is a slippy loop. The knot on the left (a Yosemite mountaineering bowline) creates a fixed loop. Note the difference between a loop and a bight – if you follow both ends of the loop into the knot they disappear into different places. In the figure 8 knot both ends go into the knot parallel to each other and stay together all the way through.

Other knot-related terms can be found in any of the standard texts on knots.

There are a few terms needed for the way knots behave that must be clarified before I start using them:

- Breaking strength of a knot is the force needed to cause the rope to snap. Almost all knots are weaker than the original straight rope, as the bending within the knot puts extra stress on the core and sheath. Obviously the force needed to break the rope depends on the original strength of the rope, so it is usual to quote the breaking strength as a percentage of the normal rope strength. For example a knot with a strength of 75%, tied in a rope with a normal breaking strength of 25kN can be expected to fail at a little under 19kN. Old, stiff rope or a badly-tied knot will lower the figure. For many knots the true strength is so variable that the quoted figures are almost meaningless – we have used the average figures from previous testing and publications but please use these as a comparative guide only! If your rigging is so tightly-loaded that the strength of a knot becomes critical, then you need to change your rigging!
- Holding strength is a property of friction knots that act to grip on something (usually another rope) and stop it from moving. The prusik knot is a common example. With these knots there is a force at which this gripping action is overcome and the knot will slip. Although usually lower than the breaking strength of the knot, in some cases it can be higher, meaning that the rope will snap before the knot starts to slide. A 6+ turn prusik knot has this property if tied in the correct diameter cord.
- Dressing is the term for the final arrangement of a knot into the correct pattern before it is loaded. Dressing is vital to make sure the knot behaves, and has the breaking strength, as you expected. Dressing a knot involves not only aligning loops and twists so they look like the diagrams in this book, but also tightening the loops in the knot and checking for errors before trusting someone's life to it. *Setting* is similar and many authors use the terms interchangeably.
- Slipping or rolling occurs when tension on two or more ropes emerging from a knot cause the rope to slip through the knot. Specifically, slipping occurs when a free rope slides through a knot, rolling is when the entire knot travels along the rope. For example a single overhand turn, tied loosely, can be rolled along a rope by pulling on it.
- Finally, capsizing occurs when uneven force on a knot makes it change shape into another stable form. This is often far from desirable and can result in the knot failing to hold the intended load. A common example is the reef knot – if you pull hard on both ends of the same rope as they emerge from a reef knot, it will capsize into a straight section of rope on one side and a larksfoot on the other. In this new shape it will no longer hold the two halves together.

3b. Permanent knots

In this book a permanent knot is not one that stays in shape when you let go! Several studies in the USA and Europe have shown that for kernmantel rope in particular, if it is left in a knot for an extended period it can take on a permanent residual stress, even when untied. Almost every caver knows that when you untie a rope that has been hanging on a pitch for a long time, the section of rope that was in the knot retains a bent and curly shape. Few realise that this section is now significantly weaker than the rest of the rope, and can remain so forever. Of most danger when tied in the middle of a rope (for example on a traverse line), long after the rope has been removed and reused and everyone has forgotten where the knots had been, it retains a point of weakness that could cost you your life. The same applies to webbing though to a far lesser extent. This residual memory is probably the cause of several mid-rope failures both in the real world and during load testing.

The same research has shown that, contrary to first impressions, if you tie a knot but never alter it, it does not weaken over time any more than the rest of the rope. The problem only arises if you untie the knot and take the 'stressed' section out of the shape it has grown to live with. The moral of this tale is simple – no long-term knots. Of course in the practical world of caving, rigging and rescue there are many knots that remain tied for extended periods, for example the knots holding your cowstails or SRT footloop together. Other knots are 'permanent' when they really should not be, for example the pre-tied figure 8 loops in each SRT rope bagged up in your store. We will neglect the issue of 'fixed' ropes installed underground at this point, as they are not the property or domain of the rescue team.

Based on these facts, I suggest adopting a simple policy on permanent knots:

1. **Permanent** knots are only used where necessary (such as for personal SRT gear or stretcher slings) and must never be untied. The simplest way to prevent this is to tape or heatshrink the tails of the rope. Do not cover the entire knot in tape, as it will be impossible to inspect it for wear, or clean it.
2. **Temporary** knots are always untied after use. Where a knot is intended to stay in place but subsequently is untied (for example a loop in the top of a bagged SRT rope) then it must be tied as loosely as possible and only dressed before use. The knot must then be untied after it is finished with.

To return briefly to the issue of in-situ fixed ropes, you can assume in the light of the current evidence that a fixed rope <u>used as it is found</u> will be as strong as it visually appears given the state and age of the rope itself. However that fixed rope must never be untied and used for a different purpose, unless the knotted sections are cut off and destroyed. As with all fixed aids in a system, it is the responsibility of the rescue team riggers to decide if the team will trust these aids or install their own. Apart from the issue of visual wear and tear on fixed ropes it is often impossible to determine how old the rope is, what previous uses it has been put to and what shock loading it may have experienced.

3c. Knots unsuitable for rescue ropework

The next chapter will discuss the knots for rescue work in detail, however it is worth making the point before we start that there are thousands of knots and they fall into three groups:

- Knots suitable for rescue ropework that have been tested and approved
- Knots that will work in rescue conditions but which have a better alternative
- Knots that are not suitable

I do not intend to cover every conceivable knot in this book, if you want to learn them all then you could start with the recognised bible, the Ashley Book of Knots. What is important is that you learn which knots to avoid before you start playing with lives.
There are two reasons why a knot is unsuitable – either it has insufficient basic strength or it behaves badly when in use. Many knots are strong enough when dressed and loaded but can fall apart if left slack. Others can capsize into dangerous configurations if loaded in the wrong direction or if trapped against something. This is far worse than a weak knot, as you may decide to rely on this unstable knot for a high-load application and suddenly find it falls apart when you need it most.

The following common knots, in use for marine, work and sport duties, are not to be used for any rescue-related ropework. There is no excuse for using them, as there is an approved knot for every possible application.

1. Reef or square knot (prone to slipping and capsizing)
2. Sheepshank (unstable when not under load)
3. Bow (i.e. double-slipped reef knot, as used for shoelaces)
4. Single classic bowline (variations of the bowline are safer, see chapter 4)
5. Overhand knot (weaker than a figure-8, which can do everything it can and more)
6. Single fisherman's knot (the double is far stronger and less prone to slipping)
7. Sheet and becket bends (weak and very unstable)
8. Round turn and 2 half hitches (prone to slipping)
9. Surgeon's knot (3-turn reef knot)
10. Waggoner's hitch (lashing hitch, bowse hitch) – has a rope-over-rope rub point.
11. Spanish bowline (double bowline is equivalent and stronger)

There are also countless knots that you may know which have never been properly evaluated for rescue loading and underground conditions. Sport cavers may well like to try out a new idea, but if you are operating as part of a legally-liable rescue organisation it is not the time to try out a Carrick bend when a double fisherman's knot is the accepted norm. You may well like the Carrick bend (it is actually a good knot, but not for caving) but you may well have to explain to a barrister why you took the decision to experiment.

The second group of knots – those with a better alternative but no major fatal flaws – is the bane of rescue team trainers. People arrive knowing these basic knots and seem to be forced by some higher power into using them despite being trained in the better options. Teaching good practice is nothing unless you eliminate bad practice.

Riggers, trainers and team members entering our world from the 'surface' or sport climbing arenas often have knots in their repertoire from this category. The unique problem of underground rescue is that the ropes are likely to be wet, muddy, covered in grit and a whole lot more that climbers or industrial access workers would run away from screaming. These problems are the main reason for putting knots in the 'could do better' groups. The classic prusik knot is a typical example – it works very well for industrial and climbing work (and rescue) as the ropes are all clean and dry. On a rope caked in clay, prusiks do not work. If your team relies on them then you can have major problems – imagine for example you create a Z-rig hauling system, working with the clean top end of a rope and deciding to put in prusik knots as you haven't got a rope clamp to hand. This will work fine, until the mud-coated bottom section of rope reaches you. At that point it is too late to change the system, you will probably have a casualty suspended in mid air, and everyone is looking at you in desperation.

The most likely cause of knot-fighting in the UK is when underground teams are on joint events with surface teams. Fire Service rope rescue teams are currently the most different in terms of the knots and techniques that they use. This is not the point to begin the debate on who is right (read on for that!) but the rigger must be aware that if he is working with people outside his team they may not know how to tie an apparently simple knot, or may create something unsuitable out of habit. Check, watch and if need be do it yourself. It may arouse mutterings of rejection amongst your team but if a rigger is properly trained he will *always* be able to tie a knot faster than he can tell someone else how to do it.

The Fire Service is often the butt of humour (even amongst themselves) for what is known as 'The Big Knot'. This is simply a method of creating a single belay point from a number of others, by running slings from each point and then tying the resulting great wad of rope into a truly mammoth single knot. Although still taught in some Service schools, please avoid it like the plague – it has far more bad points than I have time to mention and no good points whatsoever. Buy a rigging plate!

One final point before moving on to the knots themselves. In all the examples given in Chapter 4 we are tying one or more sections of identical rope or tape together. All knots work best when every rope involved is of the same diameter, flexibility, elasticity and surface friction. It is not a major problem to join a 10mm and 11mm semi-static rope mid-pitch using a barrel knot or double-fisherman, but trying to get 8mm accessory cord lashed to 13mm rock-hard kernmantle on a wet day demands only one method – tie each side to something else such as a karabiner or maillon! We also assume that you will realise this method is the only sensible option for joining polymer ropes to chains, wire rope, hangers or the back axle of your Landrover!

4. 17 essential rescue knots

As we have discussed in chapter 3 the knots available vastly outnumber the possible needs, and with comparatively few knots in your repertoire you can cater for absolutely every ropework situation. A good rigger is not someone who knows reams of obscure historical hitches and who invented them, rather someone with a total knowledge of enough knots to get by. Training people in knots is vastly more efficient and useful if the student is given a small number of knots, one at a time, and made to learn absolutely everything about each one. It is often said that a competent member of a rope rescue team should be able to tie knots blindfold but it constantly surprises me how many have to pause for thought even with the advantage of binocular vision!

There are only 17 knots in this chapter, and yet I have spent about 6 months doing through every possible ropework scenario with my colleagues and we have never needed number 18. Having said ‘only 17’ as if it is a small number, learning them all takes time and effort. The test used for riggers if I am teaching is that they must tie and untie every knot with their eyes closed (which most can do) and then recognise knots by touch alone (which very few can do). If you are in the dark for whatever reason and your life, or that of others, depends on sorting out ropes and knots then you rapidly realise how scary a lack of knowledge can become.

The knots are divided into four groups for ease of writing:

1. Knots that form one or more loops in a rope (for obvious applications)
2. Knots for joining two ends of rope together
3. Knots for fixing a rope to a solid object (using friction)
4. Autobloc knots (that can grip a rope and hence be used as a prusik device)

One or two knots can appear in more than one group (such as the figure-8) though they are put into whichever group is the most common caving application.

Without wishing to appear to be making rules, teams should think very carefully before introducing additional knots to the list. Apart from the obvious issues of familiarity when joint team incidents occur, in almost all cases there will be a knot on the list of 16 that does whatever yours can do. Each knot has been given a short character code, which we will use for the rest of the book.

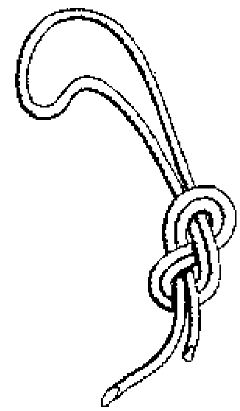
For each knot the strength is quoted as the average percentage of the original rope static strength remaining after the knot is dressed and set, and is taken either from the Lyon/HSE report [Lyon, 2001] or from our own testing. Values will be smaller for loose knots, those subjected to shock loading or those ties in wet, stiff or dirty ropes. The length lost figure is the length of new 11mm semi-static caving rope lost within the knot after dressing and loading with 80kg. It does not account for the length needed to tie the knot initially, or the length included in any formed loops. For example if you tie a butterfly knot in the centre of a 5m length of 11mm rope and the butterfly has a loop of length 30cm, then adding this to the length lost figure of 30cm tells you the rope will now only reach between points 4.4m apart.

Finally, remember one thing. Knots are the only aspect of rigging for which there exists no standard, no formal approvals and no second chance if you get them wrong.

1. Figure of 8 (F8)

Knot group:	Loop-forming		Breaking strength 65 - 75 %
Length lost:	40cm	Ease of release: good	Suitable material: Rope ☺ Web ☹

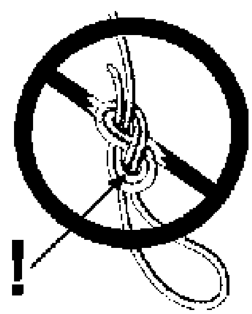
Description



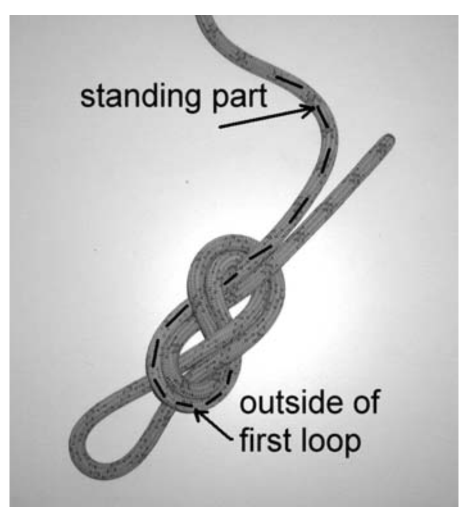
The 'figure 8' is the most widely-used caving knot, and rightly so. It is significantly stronger than the simple overhand knot (which can be as weak as 30%), is relatively easy to tie and will untie without too much effort even after loading. If tied on the bight it forms a single fixed-length loop, if tied in the end of a rope it forms a simple stopper knot. It can however be misused with dramatic consequences and is often abused by rescue professionals who lack the cavers' critical eye for safety. The figure 8 is included here for specific applications only – riggers should by habit use the stronger figure 9 knot for all rescue loads.

How to tie

The figure 8 is simple at first impression, and tying it is trivial – simply an overhand knot with a half-turn before passing the rope through the twist. The problem is that the figure 8 can be tied backwards, resulting in a loss of up to 10% of the strength. Surprisingly few people know this, so you can guarantee that at least 50% of the knots you will encounter



are incorrect. Look carefully at the picture and follow the standing part up into the knot – you can see it appears at the top of the knot, turning *above* the tail end. This is correct. If you get the knot wrong (by making the first twist in the wrong direction) then the standing part appears below the tail end. Under load, the standing part can them take up a much smaller radius bend as the tail end isn't there to act as an obstruction. This simple change to the order of the ropes can take up to 10% off the knot strength, though in tests it can be difficult to prove this reliably. A backwards figure 8 is also far harder to untie after loading – if you get a jammed knot you can bet that it will be the wrong way round.



Applications

Forming a loop in the end of a rope is the obvious application. Always make sure the tail end is at least 50cm long, and tie a stopper knot (a single figure 8) at the end to stop anyone abseiling on the tail. If you tie a figure 8 in a long bight of rope then you get two equal loops and one short tail loop. This has the advantage over the other 2-loop knots (bowlines) that there is no slipping between the loops, even under extreme tension. A figure 8 on the bight does however use a great deal of length and can be a large and unwieldy knot to tie.

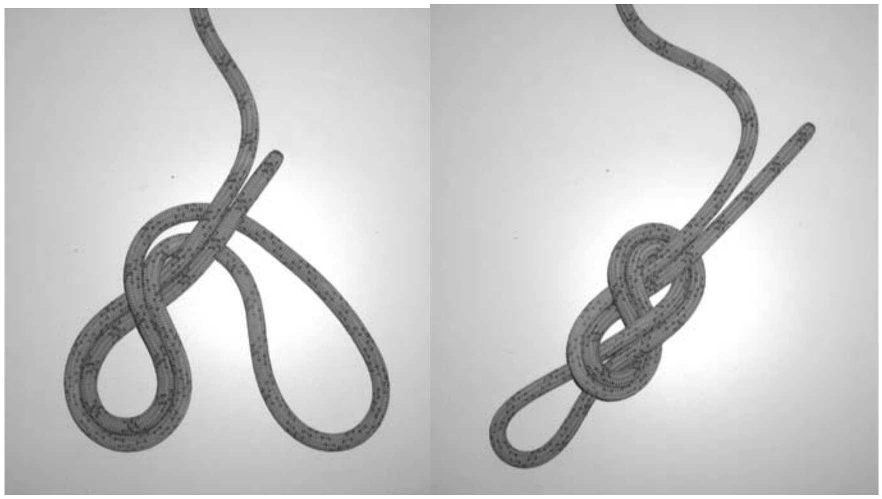
A simple figure 8 at the end of a rope as a stopper knot should always be used in preference to an overhand knot, as the latter can unroll if hit by a high-speed descent. Stopper knots must have at least 30cm of tail and be tied fairly loosely. Some teams use another figure 8 loop knot in the bottom of ropes, as it makes clipping on another length much faster. The problem is that a loop is more likely to snag when hauling ropes back in.

Joining two rope ends together by a rethreaded figure 8 (RF8) is a common alternative to a double-fisherman as it can be formed from the stopper knot. To create a rethreaded figure 8 simply tie a loose single figure 8 in one tail, leaving at least 50cm of end rope. Taking the end of the second rope, pass this back through the knot, parallel to the first rope. Dress and set the knot and make sure the two short tails are still at least 50cm long. This rethread can be used to form a very large single loop on a rope or to join two ropes mid-pitch. If used for mid-pitch knots then the lower tail (the one hanging down) should be at least 100cm long and have a single figure-8 end loop tied into it as a safety attachment point for passing the knot under SRT. Another common alternative is to create a small figure-8 end loop on each rope and simply clip them together with a maillon or karabiner. This has the advantage of creating an instant safety attachment point and being very easy to separate, even under the weight of the rope. The disadvantage is that the entire knot becomes larger, so passing it under SRT can be more difficult for novices. The choice between a rethreaded knot with looped tails and a krab-joined pair of loops is one for the rigger on scene and depends predominantly on the use for the rope (hauling, SRT or handlining). Provided the issue of SRT knot-passing is acceptable, a krab-joined rope is far better for rescue as it can be disconnected every time. A tight rethreaded knot may be slow (or impossible) to separate.

Potential drawbacks

Apart from the issue of tying it backwards, the figure 8 must not be abused. It is designed to be end-loaded (i.e. pulled along the line of the knot) and if you split-load the knot by using it to form a mid-rope loop or by loading the loop you have formed in expansion, then the knot can (and will) roll over itself again and again until it either runs out of rope or friction cuts through the material. If loading the loop across two anchors (or one large one) then the angle that the loop makes at the knot must **always** be less than 90 degrees.

Some rescue teams (and training agencies) show the figure-8 or overhand knot tied in this expansion-loaded manner as a method of isolating a damaged section of rope. This is dangerous and should never be allowed into use, as the knot will roll under stress and can then place the damaged part within the knot, leading to failure. Isolating a damaged section of rope is best done with an alpine butterfly knot as this is intended for this type of loading. If you have the time, of course, then the rope should be cut and joined in a conventional way (with a double fishermans knot) to prevent anyone accidentally using the weak isolated loop as an anchor point.



Tying a figure 8 knot on the bight (the most common application)

Joining two ropes using an RF8 rethreaded figure 8 knot (re-using the existing stopper knot on the top rope)

The double figure 8 on the bight (DF8) as shown to the left is simply a normal figure-8 loop knot tied in a long bight of rope. It takes some thought to start the knot as without practice you are tempted to end up with a very long single-loop knot instead! The knot to the left gives two identical loops that will not self-adjust between each other under unequal loading, plus it gives a *load-bearing* little loop on the bottom of the knot. This is ideal for a safety attachment point when cavers are clipping onto or off the main rope. As always, put a stopper knot in the short tail to prevent anyone using it. In the USA this is often called a 'bunny knot'. It has the same average strength as the other figure 8 knots at 65 – 75%.

The drawback with this knot is the huge length of rope needed – to create a pair of 50cm-diameter loops you will need at least a 3.5m bight of rope. The advantage is that total failure of one loop will not reduce the strength of the remaining loop, nor cause it to slip.

It is also possible to create a mid-rope knot from the figure of 8 family, and this is common with US rescue teams, where it tends to be called a 'directional figure 8'. The knot has not been so extensively tested as the other F8-derivatives but I will include it here as personally I do think it has benefits, particularly for anchors and belays.

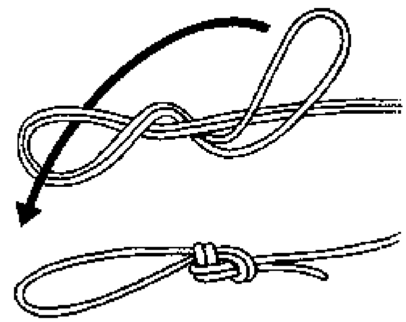
To tie a directional F8, first make a 'switchback' in the rope as shown in figure 1 below. Loop the bight of rope under the main part, and then proceed to tie a normal F8 knot around that rope, in effect capturing it within the first turn. When you pull in the slack you have a loop mid-rope that can be loaded in one direction only, but is (in theory, I have not yet seen test data) as strong in that direction as a normal F8. You must of course never allow the knot to become loaded against the 'lie' as it will cause the knot to deform, and lose a lot of the strength.

See also: Figure 9, Bowlines, Double-fisherman & Alpine butterfly

2. Figure 9 knot (F9)

Knot group:	Loop-forming		Breaking strength 70 - 85 %
Length lost	50cm	Ease of release: good	Suitable material: Rope ☺ Web ☹

Description



The figure 9 should be the knot of choice in any full rescue loading where a figure 8 knot would normally be used. The figure 8 has a place as a general working knot, but there is no realistic reason for using it when the figure 9 is identical in operation and a lot stronger. As for the figure 8, it can be tied on a single rope as a stopper, used to create a loop by tying on a bight, and also for rope joining. It is extremely easy to untie, even after extreme loading. It resists slip and rollover and can be tied in stiff and slippy ropes.

How to tie

Based on the figure 8, the figure 9 simply has another half-turn in it. Bend the rope back on itself as for a figure 8, but make a full turn rather than a half turn before passing the end through the bend. Creating bighted and rethreaded versions is identical. As with the figure 8, it is important to tie the knot the correct way round, but UNLIKE the figure 8, this knot is detectably stronger if the loaded end lies underneath the tail. It is possible to make double and directional variations of the figure 9, just as for the figure 8.

Applications

Any full rescue loaded rope where a figure 8 would be chosen. Anchor loops in belays, top knots in SRT and hauling lines should all be figure 9 knots. The thinner the rope, the more benefit a figure 9 offers in terms of ease of untying. Unlike the figure 8, the figure 9 is good at resisting knot roll when loaded in expansion (i.e. used to draw in a loop). It should still not be used in this mode, as the alpine butterfly knot is safer and better-behaved.

Potential drawbacks

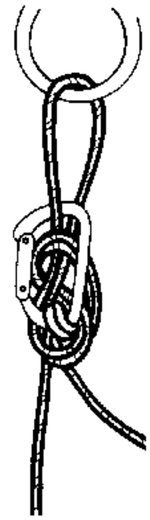
The figure 9 obviously uses a little more rope than a figure 8, but this is no significant issue. As the figure 9 is a very high strength knot, it grips it's own turns very well. This means that it must be set and dressed carefully before loading, as a high load from loose will not pull the knot together. A rethreaded figure 9 (RF9) is possible but can be confusing for the inexperienced and needs practice to do in the dark.

See also: Knots listed with figure 8

3. Stein knot (ST)

Knot group:	Loop-forming		Breaking strength 55 %
Length lost	60cm	Ease of release: excellent	Suitable material: Rope ☺ Web ☺

Description



The Stein knot is based on the figure 8 and was credited to Rudl Steinlechner, one of the best-known Alpine head trainers. It is specifically designed for tying where it is impractical to form a figure 8 around a belay post by rethreading (e.g. where both tails are very long) and the knot must be released quickly. Using a karabiner to secure the knot means that it can be tied without access to the ends or the loop itself. To release the knot completely, simply remove the karabiner. The two ends can be loaded together or independently.

How to tie

Taking both ropes in parallel, form the loop and twist of a figure 8, then reach through the loop with your fingers and retrieve a bight of the two tail ropes. Clip a karabiner through this bight, **give it one half turn** and clip back into the main loop rope to prevent the karabiner being pulled back through the hole. Dress before use. The shortest tail must be at least 50cm long for safety, and a screwgate karabiner must be used for any critical load.

Applications

As described, it offers a fast-release figure 8 knot and can be tied without access to the full rope. It cannot easily be used to create a double-loop knot and should never be used to join ropes mid-pitch. In dire emergency the karabiner can be substituted by a LONG round metal bar or pipe (minimum 30cm length and of suitable shear strength).
The Stein knot has another very common use, that of pulley locking. Imagine a long rope running over a pulley that you must tie off, turning it into two fixed ropes that can be loaded independently, such as for turning a pulley loop into twin SRT lines. Simply grip the two ropes together, create a twist and bend and clip in the karabiner. The knot is very easy to release even after loading, so makes an ideal temporary conversion.

Potential drawbacks

Needs a karabiner and can loosen without loading. It is vital that the karabiner is clipped back into the loop rope, or it can be pulled through the knot under tension. The half-turn before clipping the karabiner into the loop rope is vital to stop the knot slipping. The karabiner is not load-bearing so should never be used as a point of attachment to any other rope or equipment.

See also: Figure 8, Figure 9 and Bowlines

4. Yosemite Mountaineering Bowline (YMB)

Knot group:	Loop-forming		Breaking strength 65 - 70%
Length lost	40cm	Ease of release: very good	Suitable material: Rope ☺ Web ☹

Description

Many riggers prefer bowlines for the ease of tying (they can be done with one hand, if you practice) but the figure 9 knot is stronger and more reliable. A twin-turn (mountaineering) bowline should be the only version used by rescue riggers as the single-turn knot is far weaker and has no advantages. Using the Yosemite tie-off to pass the tail back through the knot clears clutter from the loop and allows it to be taped to the standing part for permanent knots. It also adds about 5% to the overall strength at no loss of rope length.

How to tie

Following the diagram, a twin-turn bowline is created and dressed loosely. The tail is taken around the outside of the incoming loop rope, passed under the turns and up through the forming loop (the 'hole' if you use the rabbit analogy) to emerge parallel to the standing part (the 'tree'). It is not necessary for strength, but if the knot is to be permanent you can tape the tail to the standing part.

Applications

Loop-forming where a figure 8, figure 9 or Stein knot are for some reason undesirable. As it has less strength than a figure 9, there has to be a good reason for not using that knot. Bowlines can be adjusted easier than a rethreaded 8 or 9 and are easier to untie, so the rigger must decide between ultimate strength and ease of use. One slight advantage of bowlines is that they tend to hold the loop open a bit more, so a YMB is ideal for the bottom loop on an SRT footloop.

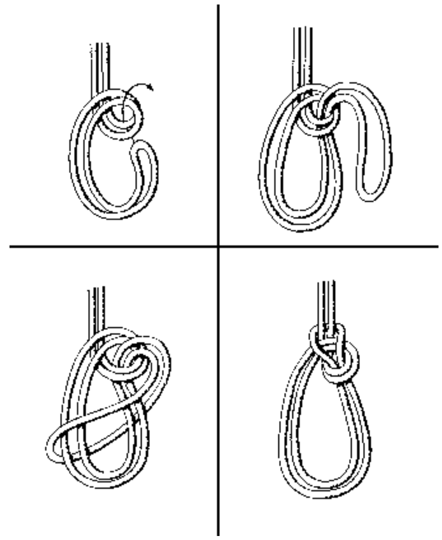
Potential drawbacks

Smaller ultimate strength than a figure 9. As with all bowlines, the YMB can loosen if not under load, especially in new slippery rope. The Yosemite tie-off greatly helps to prevent this, but if worried then tape the tail to the standing part. Remember that the emerging short tail is NOT load-bearing.

See also: Figure 8/9 and Stein knot

5. Bowline on the bight (BOB)

Knot group:	Loop-forming		Breaking strength 60 %
Length lost	40cm	Ease of release: good	Suitable material: Rope ☺ Web ☹



Description

This knot, often incorrectly called the 'double bowline', is a way of creating two nominally-identical loops in the end of a rope. It is widely used in caving and industrial access as a smaller and simpler variation on a double figure 8 knot.

How to tie

Many people are confused about how to tie the BoB as it is not technically a bowline until it is finished. You tie it differently to a single bowline, as the diagrams show.

Taking a long bight of rope, start with a single or double turn on the standing part and thread the bight up through these turns as if you were starting a bowline. Instead of taking this round the standing part and back 'down the hole' (which would give you a true double bowline), instead open the bight and flip it over the entire knot so that it ends up looped around the standing parts. This of course introduces a half-twist in each loop, but this can be dressed out.

Applications

Creating twin loops rapidly where the higher strength of a double figure 9 is not critical. Of most importance is the fact that it is easy to slide the rope around the bight, varying the relative sizes of the loops. This makes the BoB ideal for making Y-hangs that may need to be 'fiddled' after connection. If one anchor fails the knot will not fully run out, but under an extreme shock loading (greater than 6kN) the loops will self-equalise to some extent.

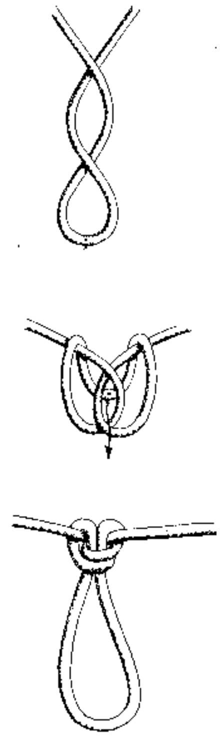
Potential drawbacks

A double figure 9 knot, although impossible to adjust, can cope with failure of one loop. As the two loops in a BoB are just one bight of rope, if they fail at a point in or near the knot then the other loop can (and will) pull through too.

See also: Figure 8, Figure 9, Yosemite mountaineering bowline

6. 'Alpine' butterfly knot (ABK)

Knot group:	Loop-forming		Breaking strength 60 - 70 %
Length lost	30cm	Ease of release: moderate	Suitable material: Rope ☺ Web ☹



Description

This knot is designed to form a single loop mid-rope, and has no other function. It must never be used for other applications as the 'figure' knots are far safer. NOTE: There are a family of butterfly knots, and it is far from clear which is the 'real' ALPINE version, as different books show different knots under the same heading. I have called my version 'alpine' as it seems to be more popularly associated with the term in the German mountaincraft books I've got, and they should know what an Alp is… hopefully!

How to tie

Taking a bight of the rope, make two twists as shown. Lift the bight over the twists and back up through the middle twist, pulling it up to form the final loop. Dress and set as required – the loop cannot easily be varied once the knot is tight.

Applications

Forming a single mid-rope knot for traverse lines, etriers and belays. Can be used to build a Y-hang or add another loop to an existing Y-hang. Remember for Y-hangs that the knot loop should be the right length so that failure of that loop will not cause an extreme pendulum fall onto the remaining anchor(s).

A chain of short butterfly knots on a rope can be used to create an emergency rope ladder.

Potential drawbacks

The knot relies on the two standing parts pulling out parallel to each other. If under loading the standing parts form an acute angle then the knot can slip. For that application, use a figure 8 or figure 9. Also, if it is only ever intended that one standing part will be loaded, then use a true end-rope loop knot.

See also: Figure 8, Figure 9 & clove hitch

7. Italian hitch (HMS)

Knot group:	Friction knot		Holding strength: ~8kN
Length lost	8 cm	Bidirectional?: yes	Suitable material: Rope ☺ Web ☹

Description

The German name for this knot, Halbmastwurf (HMS), gives the common abbreviation although it tends to be called the Italian hitch or Münter hitch. This knot is a sliding friction device and not a true knot, though it has important uses for the rescue rigging later in this book. Great care must be taken in using the HMS, as it is not suitable for the same multitude of applications that sport climbers and cavers expect. Under a full rescue loading there is insufficient friction to operate the knot by hand, and the HMS in rescue is restricted to very specific scenarios.

How to tie

The HMS is simple in outline – a pair of twists clipped through a karabiner. It is the third possible result of two parallel twists, the others being a simple pair of round turns or a clove hitch. Obviously therefore, the results of tying it incorrectly are one of these two!

The knot is designed to be capsizable under load – the load is placed on the standing part that emerges from over the karabiner and runs straight. The 'controlling' tail is used to assert variable friction on the rope by moving it towards or away from the standing part. If the duties of the two tails reverse, the knot slips over the karabiner to form an identical but reversed HMS knot. This is both useful and a potential drawback, as taking in rope encounters just as much friction as paying it out.

Applications

The HMS in rescue rigging is exclusively reserved for releasable tethers – for creating deviations, stretcher fixings or other belay points that can be lengthened under load by slipping rope through an HMS. It is absolutely vital that the HMS is not used to belay a load in the normal sense, as a single rescuer cannot control a full rescue load, even with gloved hands and a negligible fall factor. A dedicated 'HMS' shaped karabiner must be used, or at least a large oval. D-shaped and asymmetrical karabiners can cause the hitch to flip over the corner of the krab and lose the friction effect, whereas oval HMS krabs allow the hitch to flip back and forth as you change direction without risking jams in the corner. If you're running a long muddy rope, it's also worth the (substantial!) extra expense of a steel HMS krab, as it will see a fair amount of punishment.

Locking off

To ‘lock off’ and HMS so that the controlling hand can be released, grip the two tails firmly together under the knot with one hand. Taking a long bight of the controlling rope in the other, form at least two half-hitches around both ropes. Slowly remove the gripping hand and let the hitches tighten. To release, remove the hitches but obviously take hold of the controlling rope before the knot frees.

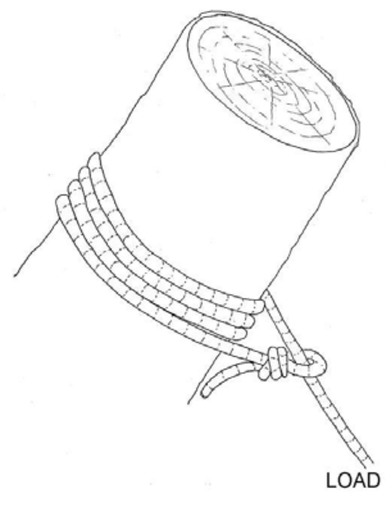
A locked-off HMS knot, using 11mm semi-static rope and an 11mm diameter steel ‘HMS pattern’ karabiner, has a breaking strength of about 50%. With the same equipment an average rescue team member with a single gloved hand can *support* a 200kg load with dry clean rope, but cannot usually arrest a fall from the same load. Even a FF ‘zero’ fall (just rope stretch) is impossible to hold with one hand.

An important and somewhat obvious point needs to be made regarding the use of the HMS for belaying. We have ruled out such use for rescue loads (200kg), though the knot is widely used for belaying a single body (e.g. while ladder climbing). Using the HMS for personal team member belaying is a decision for the team to take, but the HMS must never be used to belay a casualty, even if they are ‘walking wounded’. To use an HMS as a belay device without a prusik knot as backup fails our Sudden Death Rule, and since belaying of a casualty of any kind is a prime part of the rescue operation, having no mechanical belay devices to hand (such as autolock descenders) should never be an issue. Operation of prusik knots and HMS belays is a skilled art, especially on muddy wet ropes. Although it can work if done well, there are better and simpler options using mechanical devices.

8. Tensionless hitch (TH)

Knot group:	Friction knot		Breaking strength: up to 100 %
Length lost	--	Ease of release: excellent	Suitable material: Rope ☺ Web ☺

Description



Although this is a belaying or anchor device, it is technically a knot and so is included in this chapter. Also known as a post knot, wraparound or tree hitch, the idea is very simple. The rope (or webbing, which works equally well) is wrapped several times around a fixed object, creating enough friction so that the resulting short tail is not under any tension (hence the name of the knot). The choice of object is of course critical – it must be rough enough to provide friction but not sharp enough to damage the rope. Trees, fence posts, rock pillars and similar are common.

The major advantage of the TH is that by taking off a few turns the knot can be used to provide a friction-controlled lower action.

How to tie

Select an object with no sharp edges or corners (such as a tree or post) and if need be wrap the surface in a canvas sheet, spare tackle bag or anything to prevent rope damage. Make several parallel wraps around the object and finish by tying the loose end back to the standing part using a simple half hitch, figure 8 loop and karabiner or suchlike. The number of wraps obviously depends on the friction of the surface, but for rescue loading on an average wooden post or tree then the total length of rope in the wraps must exceed two metres. The object must have a diameter at least ten times that of the rope in order to reach the full 100% breaking limit.

Applications

Extremely strong belays (subject to a suitable object being available) that can be released gradually under controlled friction.

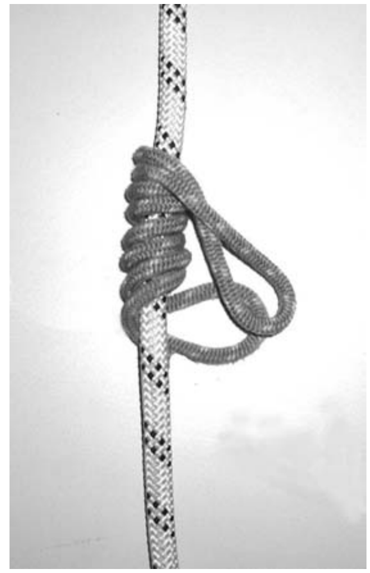
Potential drawbacks

Once tied, taking in rope to adjust the knot is very slow and painstaking. A TH is only as strong as the object it is tied to. The short 'tensionless' tail should not be used for anything loadbearing. When tying in rope or web, make sure the wraps do not overlap each other. The knot assumes that the line of pull is almost perpendicular to the object (i.e. parallel to the wraps) and of course it is vital that the object is not free to rotate. A final and obvious point is that a rope is only as strong as the weakest knot, so if you apply a TH at the tope of your rope and a bowline at the bottom, don't expect to be able to load your rope to 100% ☺

See also: Dog & tails, stein knot and mechanical belaying devices in section 5h.

9. French prusik (FP)

Knot group:	Autobloc		Slipping strength is variable
Length lost	--	Release under load? yes	Suitable material: Rope ☺ Web ☹



Description

Although this book in general avoids the use of autobloc knots, a rigger should be able to tie and use them where appropriate. Underground on wet and muddy ropes very few autoblocs work at all well, and the classic ‘prusik’ knot is next to useless. The French prusik is however very good at gripping on moderately muddy ropes.

How to tie

Using a knotted cord loop, make several wraps around the main rope, working upwards. Keep wrapping until the top tail is short enough so that when brought back down over the wraps, it lies at the same height as the bottom tail. Clip these together with a karabiner. Cord must be at least 7mm diameter and there must be at least 4 full wraps on the main rope.

To release the knot under load, grip the main line above the knot with one hand and sharply hit down on the top wrap using your fingers. The knot, if it will release, can be jerky and unpredictable so control the main line at all times.

Applications

Varied uses for temporarily taking tension off a line (e.g. to repair a hauling rig, remove a midline knot or similar). Should never be used for belaying live loads or where a mechanical device is available. All other belaying-related applications are unsuitable for rescue loads and underground conditions.

Potential drawbacks

Grip reduces on muddy or wet ropes, and under high tension it can be difficult to release. Does not work reliably with webbing. As with all prusik knots the smaller the wrapping cord diameter the better the gripping action, but of course the weaker the load that the cord can support. Using a large number of wraps (more than 6) does not increase the strength of the knot as the majority of the work is done by the outer few wraps at each end.

See also: Klemheist, dog & tails

10. Klemheist knot (KL)

Knot group:	autobloc		Slipping strength is variable
Length lost	--	Release under load? no	Suitable material: Rope ☺ Web ☺

Description

A variation on the French prusik, the Klemheist has the advantage of being effective with webbing (especially tubular web). The disadvantage is that it has less initial grip and so can slide unless gripped while the load is applied. Unlike the French prusik it is almost impossible to release under load. It is inherently weaker than an FP using identical materials.

How to tie

Using a cord or webbing sling, make several wraps as for an FP, but start at the top of the knot and work down. The top tail should be very short. After completing 5-6 wraps, thread the bottom tail up and through the top tail. When tying with webbing, make the wraps lie as flat to the main line as possible and make sure they do not run over each other when not under load.

Applications

An autobloc with the same uses as the FP, but can be tied using webbing. As for the FP it must be stressed that it must not be used for belaying a live load.

Potential drawbacks

Weaker than an FP as there is a cord-over-cord rub point where the two tails run through one another. Under loading it is impossible to release with the same techniques as work for the FP.

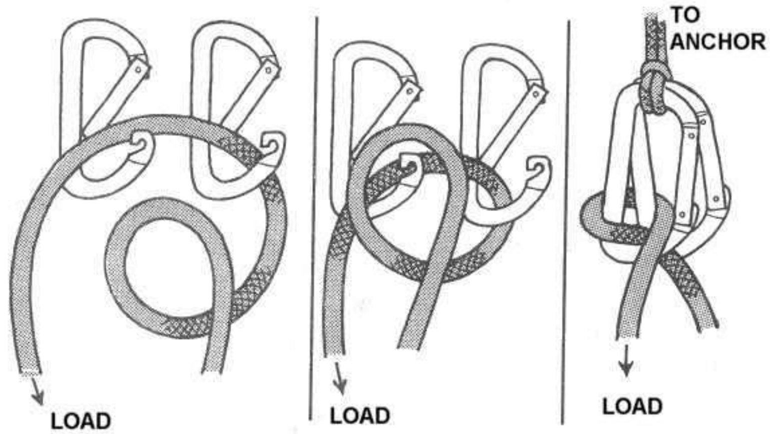
See also: French prusik, dog & tails

11. GARDA self-locking hitch

Knot group:	Friction		Slipping strength ~ 2kN
Length lost	75mm	Ease of release: good	Suitable material: Rope ☺ Web ☹

Description

The GARDA hitch was developed by the Alpine rescue teams for improvised crevasse rescue and other high-altitude work where the availability of rope clamps was sparse. The hitch uses two karabiners in parallel to create a system that allows passage of the loaded rope in one direction but not the other.



In terms of cave rescue the GARDA is not a knot that should appear in 'normal' rigging as you should always use a mechanical device to perform the function. However it is a very useful and hardly-known emergency idea when all else fails, so for our aim of creating the perfect rigger this had better be included!

How to tie

Start by securing two D-shaped karabiners together using a sling or cord and a larksfoot so that they lie parallel. It is vital that you use D-shaped karabiners – ovals will not work! Clip the rope through both gates, turn under the karabiners and clip back through the first one only. What you will start with looks just like a few turns, but dress the hitch by pushing and pulling on each side a few times and the result will be the right-side picture above.

Applications

Improvised A-block (pulley/clamp combination) when all else fails. No other real uses but a simple and useful hitch to know for self-rescue or quick gear hauling operations.

Potential drawbacks

The hitch is high-friction in both directions compared to a rope clamp and so it can place high loads on the larksfoot cord and anchors. Given this, **the load must never exceed**

100kg to avoid failure of the cord. It is however remarkably good at holding a load, and will easily support a 70kg caver without slipping at all.

The other drawback is that it cannot be released under load and cannot be used to lower off under load. It is a 100% single-shot one-direction hitch, so be careful how you employ it.

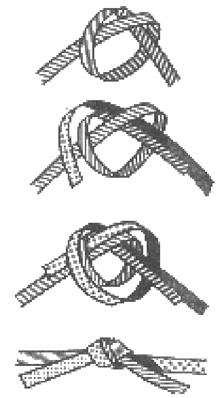
The physical arrangement of the two karabiners is vital for the operation of the GARDA hitch. You cannot cheat and use a third karabiner to clip the two together – the hitch demands that they are secured together in a positive manner. Also, the knot misbehaves on oval or HMS karabiners, though will work fine on two different-sized Ds.

See also: Italian (HMS) hitch, A-blocks and hauling systems in the next chapters

12. Tape knot (TK)

Knot group:	End-joining		Breaking strength 55 – 65 %
Length lost	4x tape width	Ease of release: poor	Suitable material: Rope ☹ Web ☺

Description



A tape knot (also known in the USA as a 'water knot') is the strongest way of joining flat or tubular webbing apart from stitching. It is the only knot suggested for use in joining the ends of webbing together.

How to tie

Firstly tie a loose overhand knot in one end of the webbing, then thread the other end through the knot, making sure it lies flat at all times. Dress the knot by easing both ends tight, so that no loose sections exist in either side.

Applications

Joining webbing of identical width. Should never be used to join ropes or to join ropes to webbing, as in both cases the knot is weak and prone to slipping under load.

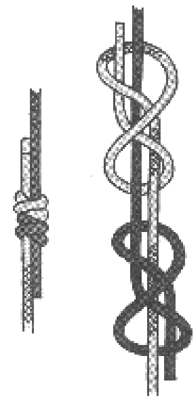
Potential drawbacks

After heavy loading, especially in tubular webbing, it can be impossible to release.

See also: there are no other knots suggested for this use

13. Double fishermans knot (DF)

Knot group:	End-joining		Breaking strength 75 - 95 %
Length lost	250mm	Ease of release: poor	Suitable material: Rope ☺ Web ☹



Description

The double fishermans (DF) knot is the best-known method of joining two rope ends, and is noticeably stronger than using other knots such as a rethreaded figure 8.

How to tie

The knot has two identical halves, each is a double-turn around the other rope with the tail tucked through the turns, as shown in the picture. Careful inspection of the diagram shows that each half of the DF is in fact a clove hitch. Learning to tie this knot quickly can be difficult, but it is equally hard to forget once mastered. When each rope has been tied, the turns are pulled tight and then the two halves pulled together, creating what looks from the 'front' like 4 loops around a straight rope.

Applications

Joining two identical rope ends to create slings or extend ropes. The tails can be made long enough to incorporate a loop-forming knot as a safety point if used to join ropes mid-pitch. If short tails are used and they are taped to the standing parts the DF will pass without trouble through large-sheave pulleys or over edge protectors.

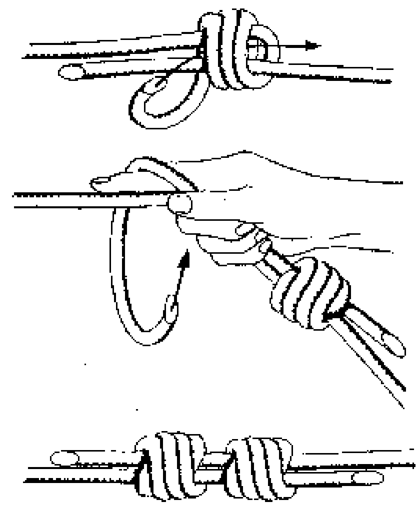
Potential drawbacks

After heavy loading, especially in very stiff rope, the DF can be impossible to release. With softer rope the best method is to pull the two halves apart and work on releasing one of them in isolation.

See also: Figure 8/9, triple fishermans, barrel knot

14. Triple fishermans knot (TF)

Knot group:	End-joining		Breaking strength 80 - 100 %
Length lost	350mm	Ease of release: poor	Suitable material: Rope ☺ Web ☹



Description

The triple fishermans (TF) knot simply a double fishermans knot with an extra turn on each side. It is often known in the USA as a 'barrel knot', though in the UK that term refers to another type of knot entirely. The TF is the only true knot that is rated at up to 100% of the rope strength.

How to tie

As for the DF, the knot has two identical halves, each now having three turns around the standing part with the tail tucked through. It is often easier to hold the loops open by wrapping them around a finger, as shown in the diagram. When each rope has been tied, the turns are pulled tight and then the two halves pulled together, creating what looks from the 'front' like 6 loops around a straight rope.

Applications

Joining two identical rope ends to create slings or extend ropes. The tails can be made long enough to incorporate a loop-forming knot as a safety point if used to join ropes mid-pitch. If short tails are used and they are taped to the standing parts the TF will pass without trouble through large-sheave pulleys or over edge protectors. For many applications the smaller DF will be adequate and is quicker and simpler to tie and release, though the TF has better holding ability in very slippery ropes or when joining ropes of slightly different diameter. Neither the DF nor TF should be used to join ropes where the diameter difference exceeds 2mm.

Potential drawbacks

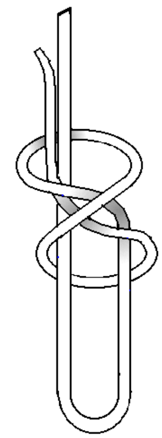
After heavy loading in any rope the TF can be impossible to release, to the point where if must be cut from the rope. It also uses more length than a DF.

Note that if you tie three turns on one side and two on the other, the knot (which has no name!) will only be as strong as the weakest (DF) side.

See also: Figure 8/9, double fishermans, barrel knot

15. Barrel knot (BK)

Knot group:	Loop-forming		Breaking strength 65 - 75%
Length lost	75mm	Ease of release: moderate	Suitable material: Rope ☺ Web ☹



Description

The ‘barrel knot’ in our definition is the name for a knot using one side of a double fishermans knot to create a slippy loop in the end of a rope. In the USA, the term ‘barrel knot’ is sometimes used to refer to a triple fishermans knot.

How to tie

First a bight of rope is taken, then as for the DF a clove hitch is tied around the standing part using the tail. This creates ‘half’ of a DF. The resulting loop is slippy, meaning that under load it contracts until the loop is tight around the object within it.

Applications

A compact knot which uses very little rope, the BK is commonly used to create the end-loops in cowstails and stretcher handling ropes. It should NEVER be used to create a tie-off loop in the end of a main line, for that you should use the ‘figure’ knots. Under dynamic loading the slippy nature of the knot can reduce peak loading forces, which is one reason it is a good choice for cowstail knots.

Potential drawbacks

The loop must be kept as small as possible before loading, or the friction as the loop slips can easily melt the rope. Also obviously the knot does not leave an open loop under load, so another karabiner cannot be added into the loop without releasing the load.

See also: Figure 8/9, double fishermans knot

16. Clove hitch (CH)

Knot group:	Loop-forming		Breaking strength variable
Length lost	--	Ease of release: very good	Suitable material: Rope ☺ Web ☺

Description

The clove hitch is included in this list with caution, as it is not a true 'knot' and has highly unpredictable behaviour in the hands of the inexperienced. It is however the basis of many other knots (the fisherman series for example) and is valuable as a rapid method of temporary fixing. The CH attaches a rope to a fixed object (the 'former') and will vanish if the former is removed.

How to tie

Wrap the rope twice around the former, then tuck the tail from the lower turn over the bottom rope and under the top one, as shown. The strength of the knot and action under load depends critically on the nature and size of the former. With a large rough former the knot will hold to breaking point (approx 45 – 75%), with a smooth or small former the knot will tend to slip at varying loads. When tied in 11mm static rope on a karabiner the knot will tend to slip under high dynamic loads but break under static loads at about 55%.

If the former is open-ended (such as a spike or karabiner) then the CH can be formed by making two loops in the rope, slipping the top loop under the other (without twisting it over) and dropping the pair of loops over the former. If you twist the loop you will make an HMS.

Applications

Temporary fixing of a rope to a fixed object. Should NOT be used to create fixed traverse lines, as the butterfly knot is stronger and leaves a fixed loop. Should never be used to create an end-loop in a rope.

Potential drawbacks

The strength and slip of the knot depends on the former. Allowance must be made for possible slipping under dynamic loads – neither tail should be less than 2 metres in length.

See also: Alpine butterfly, tensionless hitch

17. Dog & tails (DT)

Knot group:	Autobloc		Breaking strength 75 - 95%
Length lost	--	Release under load? yes	Suitable material: Rope ☺ Web ☺

Description

The dog & tails is an autobloc specifically designed for securing a line to a fixed belay point, and can be used to replace mechanical devices if they are not available. The knot does not cause damage to the main line if shock-loaded as the gripping action is distributed along the rope.

How to tie

The centre of a long length (2m+) of cord or webbing is fixed to the belay point, then a series of alternating under- and over- crosses are taken around the main line, ending with a reef knot. The number of crosses is chosen depending on the friction characteristics of the two materials. For 9mm cord and 11mm kernmantel rope, 10 crosses are sufficient.

Under load, the crossed section expands and grips the main line. To release the device under load, push the crossed section back towards the belay point. Be aware that tension will be released suddenly and completely. The knot can be formed from two webbing slings joined at both ends by karabiners, or from static rope of the same diameter as the main line, though the best compromise between friction and strength is cord of 2mm smaller diameter than the main line.

Applications

Belaying a line being taken in from a hauling system where mechanical devices are not available. Most likely application is in belaying a rope of unusual diameter. The dog & tails works reasonably well on non-rope material such as chain, tubes and poles etc. and is the preferred method of belaying hoses or flexible pipes. It works equally well on kernmantel or hawser-laid rope though grips poorly on wire ropes and cables, mainly due to the smooth surface and presence of oils.

Potential drawbacks

Time-consuming to tie and untie, abrupt release action under load, needs attention and skill to control when taking in. If used for a long-distance haul be alert for signs of friction damage to the cord or webbing.

See also: French prusik, tensionless hitch, klemheist

5. Anchors and belays

An anchor is a fixed object to which ropes or equipment is attached, whereas a belay is a device designed to control a rope under a shock loading. Many people use the term ‘belay’ when they should use ‘anchor’, the only case where they are equivalent is when the belay device is simply a rope wrapped around a live rescuer who is not himself fixed to anything else.

Cave rescue ropework naturally relies in the end on points of attachment from the rope to the rock, and the ultimate strength of the entire rig depends on that of the anchors. The underground environment is also far from ideal in terms of natural anchors, especially where they are most needed. Surface rescue teams can always resort to a judicially-placed 4x4 or large tree, whereas in cave rescue the immediate environment often only offers rock (of varying quality). The constraints on physical space and the need to communicate often mean that the rigging must be in a particular place (e.g. at the head of a pitch) and good anchors 50 metres away are not an option.

Having said that, often the main hauling pitch in a rescue is the entrance, where ‘surface’ anchors will be available. In rescue there are two factors influencing the choice and use of anchors, and these are often in direct conflict. Of primary importance is strength and reliability, and then comes speed of placement. Obviously in every situation the strongest possible anchor system would be a massive number of resin hangers distributed around the area and linked together, or a huge rolled steel joist concreted across the passage. Neither would be ready inside of 24 hours and the casualty would not thank a team for taking that long to get them out. As with the medical evaluation of a casualty determining speed of removal, the specific situation decides the compromise point between strength and speed.

Rescue riggers will often find in-situ anchors placed for sport caving (resin hangers or bolts most obviously). Reliance on these rather than installing new anchors is another question of speed, strength and experience. Questions must be asked not only of how strong the anchor is supposed to be, but how well it was actually fitted. Clearly there is little issue of a rescuer knows the history of a bolt and can vouch for its security. There have already been several cases in the UK of badly-placed or old bolts (usually self-drill caving bolts) which have failed when subjected to rescue loads as part of testing programmes. This has led to the adoption of the resin P-hanger as the only reliable bolting product in UK caves, though of course in a rescue the time delay of 8 hours for the resin to set is prohibitive if none are in-situ.

It must be stressed that as part of a rescue, use of any ‘suspicious’ anchors must be forbidden. The legal arguments raised by any subsequent charges of negligence could not justify use of an anchor that the rigger doubts is suitable for the intended load. However, the decision to run with a group of lower-strength anchors rigged appropriately, or waiting while a set of new ‘bomb-proof’ anchors are installed, is one for the rigger alone. It is in this situation that there is no substitute for training and experience.

5a. Loads on anchors during hauls and falls

Recently a great deal of work has been conducted to measure the dynamic forces placed on anchors during ropework, partly made possible by cheaper load cells! The best studies so far are by Lyon for the HSE and Technical Rescue Magazine. These both used real-time dynamometers to measure the loads during typical ropework operations. The Lyon tests used a normal load, but the TRM belaying tests used a 200kg rescue load.

During normal loading of a rope the force transmitted to the anchors is hardly ever exactly equal to the weight of the load, unless everything remains totally stationary. Motion of the load (either by moving it along the rope as in SRT or by moving the rope as in hauling) requires acceleration against gravity, and the force to accomplish this must be transferred to the rope and the anchors as this is the only fixed point of connection. The amount of extra force depends on the acceleration – so clearly a slow gradual haul or careful SRT descent keeps the instantaneous load close to the lifted weight. Jerky movement or any type of fall will cause high acceleration and similarly high dynamic loads. Remember that forces are not averaged over time – the effect of a 50kN force on a rock bolt will be the same irrespective of if it lasts 10 minutes or a thousandth of a second.

With a dynamic system of ropes and equipment the way an impulse force propagates through to the anchors is complex. If a free-falling mass is brought to rest by the end of a rope then the *energy* of motion must be transferred up the rope. This energy is equal to the force multiplied by the time it exists for (in simple terms) so it can either result in a long-lasting but small force on the anchors or a short and large force. The deciding factors are the elasticity of the ropes and the friction between the mass and the anchors. The more elasticity and friction the lower the peak load. Energy is transferred out of the system at friction points, so the more you have the less energy reaches your main anchors.

In rescue rigging we are not overly concerned with the dynamic forces caused by a free-falling load, for two reasons. Firstly, calculating the peak forces is complex and often impossible on paper, as all the factors of friction, stretch, angles and lengths must be allowed for. Secondly, all our rigging systems should be designed to minimise the possibility of a true fall. With a 200kg rescue load very few items of equipment will be able to withstand a fall of anything over FF0.33, it is beyond practicality to design rigging to allow for this. Remember this motto from a US-based caving club magazine:

Climbers use fall protection, because they expect to fall – it's part of the fun.
Cavers use fall prevention, because they don't want to fall, it's not part of the fun.
Casualties use fall prohibition, because if they fall they'll die. Nobody's idea of fun.

What matters to us, discounting the free-fall scenario, is the extra force applied during normal operations (hauling, lowering, climbing etc), as we must 'budget' for this in our calculations. It's no good putting a 200kg load (which weighs 2kN) onto an anchor that can only support 2.5kN and then proceed to jerk it about with a hauling rig. Eventually your invisible load meter will pop over the 2.5kN limit and you will see shiny alloy components whistling past your knees.

The following table is taken from several dynamic tests published over the last 10 years showing the range of loads applied to anchor points during rope work. The load weight is simply the mass in kg multiplied by the acceleration due to gravity, **g** (9.81) and the instantaneous peak forces are given. In all cases the average force is equal to the load weight, as the load is (overall) moving at a constant rate. We have also expressed the maximum force as a percentage of the load weight.

Operation	Load weight N	Minimum N	Maximum N	Maximum as %
SRT descent	750	650	900	120%
SRT ascent	750	350	1050	140%
Bad SRT[1]	750	350	1600	213%
Simple hauling[2]	2000	1800	3000	150|%
Simple lowering[3]	2000	1900	2300	115%

1. SRT ascent and descent using a deliberately poor and jerky technique.
2. Manual raising of a load using no compound pulleys. Rope passed over a single pulley on an A-frame, forming an angle of 90° between hauling party and load. Force sensor positioned between this pulley and A-frame mount. Typical of a pitch-head scenario. Load stops moving between each pull.
3. Same setup as (2) but lowering through a Petzl I'D mounted where the hauling party was standing. Load stopped and started several times using the I'D as a brake.

From the table, several points are clear. Hauling or SRT ascent naturally generates slightly higher peak forces, as the load is trying to accelerate upwards using the rope to pull against. In general for movement on a rope where the technique is controlled and 'normal', the peak forces should not exceed 150% of the static demand. What is striking, and important, is that with bad technique the peak forces can become enormous. Motto – a smooth technique is far more important than the direction you are going! The (obvious) worst-case scenario is a hauling operation using a jerky, bouncing technique on a short rope (so the natural shock-absorbency of the rope is minimised).

I will not dwell on the mathematics of peak impact forces, elongation ratios or dynamic belaying, as applying a mathematical model to a complex rescue system is not practical on paper or in a cave. There are numerous texts from the climbing world that adequately cover the mathematics of free-falling arrests, but realistically if your casualty every goes into free-fall you have converted a rescue into a recovery.

5b. Natural or found anchors

Underground this usually refers to suitable rock shapes (pinnacles, holes etc) that can provide an anchor by looping or threading a webbing sling. On the surface 'natural' includes anything that is not intentionally moved into position.
In mined passages often 'natural' placements can be found even though they are man-made, hence the occasional use of the phrase 'found' to refer to non-geological anchors. Examples include shot-holes that pass through a portion of rock and re-emerge into the passage, in-situ structural steelwork or heavy objects such as winches, pumps or trains.

Natural anchors can be the most or least obvious in terms of strength. A clear eyehole in solid undisturbed rock will probably outlast every item of rigging that could be fixed to it, but a seemingly-solid pillar of rock may have microscopic fractures within it. Without detailed measurement, core sampling and testing it is impossible in a rescue situation to determine the true load capacity of a natural anchor. Experience can give a good 'eye' for what is safe and what is not, but in all cases a healthy scepticism is needed.

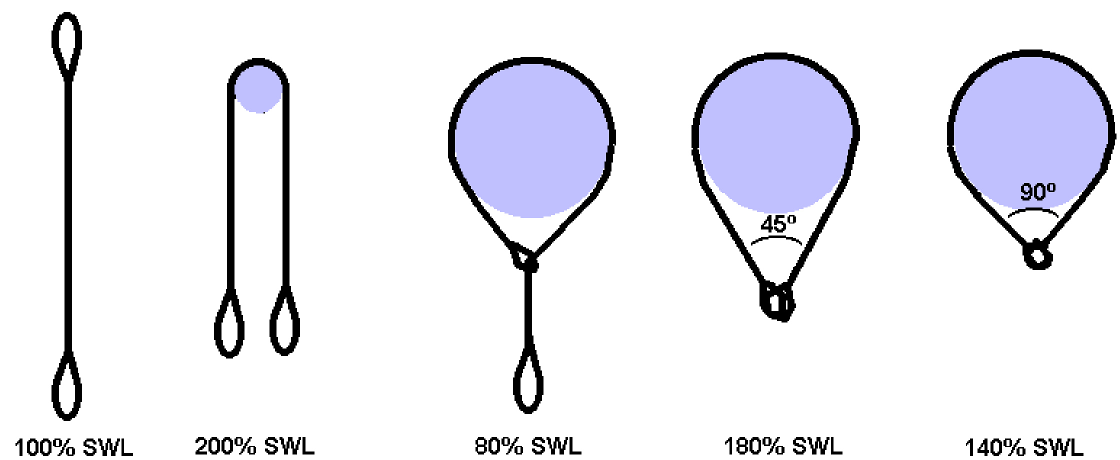
The two most important areas of difficulty for natural anchors are stal formations and mines. Cave formations (stalagmites or columns) can appear strong by virtue of size, but often are not fixed to the solid rock of the cave floor. Many grow over thin layers of mud or flowstone, leaving a weak fracture plane at the base. Of course if you are faced with a 100cm diameter column in a 2m high passage, you can assume that even if it is not very well rooted it is certainly heavy enough to resist any urge to move. Smaller columns (and especially stalagmites where there is no 'propping' effect from the roof) must be treated with extreme caution. Remember above all else that you are now designing a rigging system that will impose far higher peak forces than the countless teams of cavers who have used the route in years gone by. The fact that a shard of rock will work for a single caver on SRT and gets a mention in the guidebook is not a test certificate for a 250kg loading!

In mines the rigger is faced with the fact that every rock surface available is the result of blasting. Shockwaves can introduce microfissures in rock so that a seemingly-solid face may peel away in sheets when loaded. Of specific concern is the effect called 'plating' where a drilled bolt can pull away a thin circular plate of rock that has been split from the solid wall by the effect of blast wave cavitation. Rocks with a homogeneous microstructure such as limestone are more susceptible to plating than you may think, and the worst effects can occur where surface quarrying nearby has transmitted detonation shockwaves through the rock. Layered rocks such as shales and slates are obviously prone to plating, and sometimes just the vibration from drilling a hole can bring off the top layers of a face. The rule with a surface that plates is that deep does not mean safe – plating can occur just as easily at the bottom of a 60mm hole as a 25mm hole, all that changes is the size of the rock that lands on your foot. Some riggers argue that resin anchors prevent plating by removing the pre-stressing of an expansion bolt, but my argument is that if the rock wants to slice into chunks, it will do so whatever you stick in the hole.

'Found' anchors in mines – old steelwork and mining equipment – must be treated with similar caution. Firstly use your judgement (and a little mechanical engineering) to decide if the object would take the required load if it were in perfect condition. Massive 30cm steel I-beams are obviously suitable, but when faced with something of the dimensions of scaffolding bar the question can be marginal. Once you have passed an object, you must work out what state of repair it is actually in. Check depth of rust, welds and junctions. Of most importance is the point where the beam attaches to the rock. Some beams set into recessed holes will be as strong as the day they were installed. Others may have relied on wooden wedges, old chains or wires, piles of boulders or something else that is no longer even there. In older mines the effects of seismic activity and nearby quarrying can displace beams or supports, so never assume that a large beam is always a strong beam. As well as the ravages of time almost all abandoned mines were subject to stripping and salvage, so a critical strength member may have been removed many years ago. The final point is that you may be loading the beam in a different direction to that fort which it was installed. Horizontal pulls on roof support beams may bring the entire passage crashing about you.

Whenever attaching to any natural or found anchor, it is obviously important to protect the rope from sharp edges, rust or rock fragments. Ideally webbing slings should be used over the top of some padding material (empty tackle bags, conveyer belting, canvas sheet, etc.). Heavy-duty industrial slings, chains or wire tethers are often used as 'indestructible' devices, but remember that for wire tethers and chains there are issues of loading over edges. If you have to fashion a sling from the main rope then some protection is vital. If the rope is to move (for example in a tensionless hitch) then the padding material must not deposit anything on the rope as it rubs over it. Canvas or old carpet is fine, rubberised material or plastic sheeting is not. Once a rope has had melted rubber smeared along the sheath it is destined for the bin.

A strop (a single length of wire rope or webbing with a formed eye at each end) or sling (a round loop, sewn or swaged) must be marked with the safe working load (SWL), which is 20% of the tested breaking load. The peak load that you can apply to a strop or sling depends somewhat on how you use it, as shown below in the diagrams. Simple rule of thumb is that gentle curves increase the available SWL, tight curves and edges decrease it. When using webbing underground another factor is the surface texture of the 'former' (the object around which you are fitting the sling or strop). A rock pillar may well be round in general terms, but a few scallops on the back face could mean that your sling is loading over a dangerously sharp ridge. Think padding, padding and more padding – even for wire rope it is good practice to apply some kind of padding – to protect the former from damage as well as the wire rope! You may be rescuing someone, but a second to add a bit of canvas around a spike of rock will prevent people marvelling at saw-marks for the next 3000 years.



Often the sharpest 'edge' is where your sling or strop connects to your rope. Wire strops should have maintained eyes – the wire should be held in a teardrop shape by a steel insert, which also stops the wire getting damaged by abrasion on the inside surface of the eye. Webbing strops often have their eyes protected by an additional covering, but in all cases three rules apply:

1. Never tie a rope directly into the eye of a strop, or around a sling.
2. Interconnect using a karabiner, shackle or ring with the largest possible diameter
3. With slings, make sure the junction is clear of any edges or sharp bends.

The only other rule is direction of loading. When you wrap a wire rope or webbing sling around a former (with or without padding) and load it, you create a very high-friction contact between the two. Swinging the direction of pull while under load is generally a bad idea, as one of two things will happen. Either the strop will slip, sawing against the former and either damaging it or the strop, or even worse the friction will hold, and you will end up loading one end of the strop more than the other. Eventually, as you move the load further from the start direction, the load in the 'slack' end will drop enough that the frictional grip will be lost, resulting in a rapid slip of the strop and an unexpected (and possibly catastrophic) shock load on the system.

Using a sling instead of a strop is one way around this problem – relying on the idea that the connecting karabiners can slide along the sling rather than forcing the sling to rotate. This is fine for occasional uses (such as diverting a pull when a load reaches the top of a pitch) but if your rigging system generates a regular sawing motion, your webbing may not last as long as you hope!

One final note – if you have to join two or more webbing slings together, never use the 'larkshead' knot as this seriously reduces the strength of the combined slings. If at all possible use a karabiner or maillon to join webbing to anything, including more webbing! If you have no choice, then try to insert something smooth and round into the loop of the larkshead before it tightens (even a bit of rope will do) – no gain in strength but makes it far easier to prise apart later!

5c. Props

This category encompasses any anchor created by a pole, beam or spar placed across a passage. Often used when the rock surface is too friable for bolting, examples range from a simple scaffolding bar placed across an open hole to an Acrow prop secured across the walls of a passage. Props are often underused in rescue, mainly due to the physical size of the objects. Neglecting the salvage of in-situ metalwork, which comes under the auspices of 'found' anchors, props usually involve solid poles (scaffolding) or adjustable devices such as Acrow props.

All rescue teams should have a collection of props for their other primary use – that of supporting a weak roof. During digging or work in an unstable area they are vital for protecting the excavated ground and those doing the excavation. However as anchors they are also invaluable. Assuming that a suitable passage exists, providing two walls at a separation compatible with the props available, then a secure prop can be fitted in less than a minute and provide strength comparable to resin anchors. Prop placement is somewhat of an art but can be vital in areas of friable rock such as mines. Experiences in North Wales slate mines by the NWCRO have shown that props are often the only possible anchor method, given that bolts do not hold in slate (think plating!) and natural anchors are invariably non-existent.

A typical 'Acrow' prop has a threaded expansion system comprising a collar on one part that screws outwards along a threaded sleeve. The second part of the prop runs inside this collar and sleeve and is fixed to it by a pin. As the collar rotates against the pin the overall length of the prop increases. Collars usually have built-in handles. There are two broad options for the shape of the end of these props – conical pins or flat plates. It is more difficult to find the pin designs commercially, but often props have flat plates that are removable, so pins can be fabricated and swapped if required.

- **PINS** are of most use on irregular rock where the end of the pin can be inserted into a depression. Once expanded between two such depressions, a pin-ended prop is the strongest. They do not work at all on smooth rock.
- **PLATES** work well on smooth rock but a rubber friction pad between the plate and the rock is vital. This can be fabricated from a square of conveyer belting. Rubber sheet has been found better than wood blocks as it is more conformable to small irregularities in the rock surface. Plates can work on irregular surfaces but are not as strong as pin-ended props.

Apart from the use of rubber sheeting with plates, one simple but useful modification is to bend the corners of the plates outwards (towards the rock). Only a small section is bent, creating a little triangular spike that helps to dig into the rubber sheet. This modification also increases the grip against wooden beams or sheets. Plate-ended props are not suitable for direct use against a rock surface as there is a tendency for only one or two points of the plate to make contact. Under load the entire prop can rotate about these points and in some cases will come free. In an emergency any compressible substance (a folded tackle bag or pair of gloves) can be used if the rubber sheets are lost.

Correct rigging to a prop is important. For sport caving a simple sling around the prop somewhere useful will suffice, but for rescue loads things must be dome more carefully. Wherever possible the loading should be distributed equally to each end of the prop to avoid any tendency for it to be twisted free. A long sling or rope loop from each end of the prop meets at the centre to create a triangular anchor web. This central point must be a free-running joint rather than a fixed knot, so that any change in pull direction can re-equalise the length of each side of the triangle. It is also important to make sure that the slings do not impart any rotation to the prop – especially for plate-ended props where that action could move it from position.

5d. Rock bolts and hangers

Without wishing to cause confusion the term 'hanger' in the context of this book refers to the visible exterior part of any anchor that is placed by drilling a hole in a rock surface. The sleeve, bolt or pin that enters the hole is the 'bolt'. Some hangers are one-piece objects such as the resin-fixed P-hangers and eyes, we shall call all these 'hangers'.

In UK caving, drilled rock protection can be divided into four types:

1. Resin hangers – stainless steel P-shaped bar or cast eyebolts secured by epoxy resin. For these the term 'bolt' does not really apply as the object is a single piece of steel.
2. Self-drill bolts – M8 alloy sleeves with teeth, designed to hand-cut a 12mm hole using a proprietary holder. Secured by an expansion plug and fitted with a separate steel or alloy hanger using a short M8 machine screw. Occasionally found in M10 capacity but this is rare as they take much longer to hand-drill.
3. Drilled expansion bolts – sleeves of varying diameter, secured by expansion and fitted into a hole created by an electric drill. The most common is an M8 sleeve, which fits into a 10mm diameter hole. Fitted with a separate hanger plate or (as for the Petzl Longlife P38/39) an integral hanger and expansion sleeve unit.
4. Anything else! Cavers have used almost every industrial, domestic and home-built method of bolting and it is not unusual to find Rawlbolts, steel studding held in with resin, wooden pegs and screws – the list is endless. Clearly in a rescue situation the use of any unusual design of bolt is bad practice, as the performance (and skill of the fitter) cannot be predicted.

Bolts used in rescue are an area of some debate and controversy. Some modern bolts are perfectly suitable to the large rescue loads, other (and older) models are certainly not. The UK programme of resin P-hanger installation undertaken by the CNCC/NCA is in part an attempt to address this. If a rescue rigger is faced with a pitch where P-hangers are in place then for all reasonable situations they can be assumed adequate. Clearly if there are none in place then there is no possibility of fitting them, as the resin takes up to 12 hours to fully cure. The other problem sometimes faced is that rescue rigging requires different (and more) anchor points than sport caving. An SRT pitch may have only two hangers at the head for sport rigging, but a dual-rope hauling system will require at least 4 at the pitch head and a further 4 some distance back. It is vital that a rigger does not apply multiple loading to anchors simply from lack of options. There is always an alternative (props, drilled bolts etc.). Luckily in many cases the installation of resin hangers has allowed for rescue, fitting additional hangers where needed.

The resin P-hangers installed under the CNCC/NCA anchor replacement policy are inspected and maintained by the installation teams. Fitters are trained and the anchors and resin are fully approved and traceable. As a result the strength of any 'official' P-hanger can be pretty well guaranteed. The most common sport caving anchors in the UK were the M8 self-drill bolt and Vrillee M8 alloy hanger whose strength was far from predictable. These are still in common use and many caves are festooned with hangers or empty bolts of this type. The CNCC/NCA anchor replacement scheme is working through well-used systems and installing DMM Eco-anchors in direct replacement, removing all old bolts in the process. This is a long-term project involving a great deal of work by those involved and can only be applauded, however the commercial basis of the policy results in only DMM anchors being used. Whilst these are perfectly suitable for sport caving there are obvious questions when higher-strength anchors are available from other sources. In rescue it does not pay to adhere to any commercial limitations.
As detailed elsewhere in this book typical shock loading on a main anchor during a rescue load fall (200kg, FF0.3) is about 7 – 12 kN. Our baseline requirements for anchors are therefore 20kN in the direction of load. It is assumed that a shock loading in excess of 15kN is likely to cause failure of connected equipment (karabiners, slings etc) and so it would not be normally possible to apply a 20kN load to an anchor except in the rare case where two simultaneous failures cause a double shock load through two separate rigs.

Self-drill and pre-drill M8 sleeves

The common M8 caving expansion sleeves, either self-drilling or fitted into a power-drilled hole, were until the arrival of cheap resin hangers the main protective option in UK caves. Many hundreds of these anchors remain in place and many are still used. There are two main problems with these devices for rescue:

1. The manufacturers of these sleeves did not intend them to be used for sport caving, and as such they were never intended for the abuse they receive. SPIT, for example, specifically state that both self-drill and pre-drill sleeves are not suitable for applications involving shock loads or dynamic loading.
2. All these industrial sleeves are designed for use in concrete, and only in concrete. Figures quoted by manufacturers always refer to the strength in standard 50MPa concrete and some (SPIT included) specifically state the anchors are not suitable for use in natural stone. Even Petzl's published figures for caving anchors are based on 50MPa concrete rather than limestone.

The concrete issue is quite a problem. '50MPa' refers to the modulus of rupture, in essence the ability of the rock to resist breaking apart under stress. It is measured by trying to break a rectangular beam of rock by bending it in a 3-point load rig, and the lower the figure the more likely a sample is to break apart under load. For expansion anchors the usual route of failure is that the rock 'plates' – a conical section of rock splits away, centred on the anchor. This would not be too much of an issue if it were not for the fact that concrete has a rather high modulus of rupture due to the aggregate nature of its composition. Limestone, on the other hand, is quite poor. Typical MOR figures for plain white limestone, provided by stone quarries in the UK, vary from 5.5MPa to 15MPa, with some values halving when the rock is very wet.

So, based on the table at the end of this chapter for SPIT sleeves, we could assume a shear-loading limit of about 2.7kN in concrete and approximately 1.5kN in limestone. This is probably suitable for sport caving but is nowhere near our 20kN rescue limit. Even a set of 10 M8 sleeves rigged in unison is questionable!

M8 expansion bolts with alloy hangers are unsuitable for use in rescue ropework

Other options

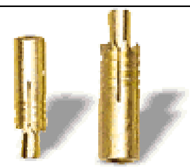
Using a larger size sleeve is one idea – but from SPIT's data again their M20 sleeve is still only rated for 12.5kN in tension. Not exactly much improvement for a huge increase in hammering time!

Resin anchors are clearly more reliable, as ultimately any drilled bolt is entirely dependent on the skill of the driller and the extent of damage done to the rock. Drilled anchors typically penetrate by a maximum of 50mm and so are prone to surface plating of weak rock. Resin anchors usually penetrate by 100mm+ and so are less affected by any weak surface region. The drawback for immediate rescue use is that they take time for the resin to set. Usual quoted times are between 8 and 24 hours, though special-purpose rapid rescue resins are available that can set within 30 minutes. Even this is too long to wait in a cave situation. There is however a call on many rescue teams to pre-install specific anchors for rescue in popular sites. In these cases resin offers the best possible strength, long life and ease of placement. The CNCC/NCA system uses the DMM Eco-anchor but it is worth considering other types. True 'eyebolts' such as the Collinox, Bat'inox and Tig are best suited to parallel loading or rigging points designed for use in any direction. P-hangers such as the Eco and Resinox have proven capable of surviving angled loadings but are specifically designed for loading in the direction of the 'P' only. Rescue loads in any other direction are unlikely to cause failure but can bend and deform P-hangers.

The motto, as with any caving equipment, is that it is worth checking a wide range of manufacturers, as the obvious main suppliers may not always be the best in terms of performance or value.

The next pages show a table of common commercial anchors and their performance, the data for which is taken from the manufacturers' published literature.

Anchor		Fixing	Hole & (mm)	Material	Tensile strength	Shear strength
	Petzl Vrillee P04	M8 bolt (supplied)		Alloy	12	18
	Petzl Coeur + (2 size options)	M10 / M12 expansion sleeve (supplied)	10 / 12	Stainless steel	18	25
	Petzl Longlife P38	Expansion sleeve	12	Stainless steel	18	25
	Petzl Collinox P55	Resin	10	Stainless steel	25	25
	Petzl Bat'inox P57	Resin	14	Stainless steel	40	40
	Fixe Bichrome+ (3 size options)	M8,10,12 bolt		Steel	15	22
	Fixe Inoxe+ (3 size options)	M8,10,12 bolt		Stainless steel	35	40
	Fixe Tig	Resin	10	Alloy	25	30
	Fixe Tig Inoxe	Resin	10	Stainless steel	36	40

	Kong wide-eye+	M12 bolt	14 / 16	Stainless steel	18	25
	Kong Resinox 898.10	Resin	12	Stainless steel	20	25
	DMM Eco-anchor	Resin	18	Stainless steel		
	Fixe Goujon 3 lengths (70,90,95mm)	Expansion sleeve	10	Stainless steel	17/23/23	25
	SPIT GRIP M8 expansion anchor (pre-drilled fixing)++	Expansion sleeve	10	Steel	2.7	1.5
	SPIT SRD8/MF8 self-drill expansion anchor++	Expansion sleeve	14	Steel	2.7	2.7

+ These hangers are not supplied with a bolt or expansion sleeve.
++ The SPIT sleeves are typical of those used by cavers. Strength figures are for 23MPa concrete, as these anchors are not designed for use in limestone. Note the very low strength figures!

Hole diameters are not given for bolted hangers as the figures depend on the model of anchor sleeve used.

Rated strengths for resin anchors are based on correct placement in standardised 50Mpa high-modulus concrete.

Figures for bolted anchors are the rated strengths of the HANGERS ALONE and do not account for the strength of the underlying expansion sleeve. Often these sleeves can fail at very low loadings. The hanger strengths are those forces required to break the metal plates themselves, or to pull the head of the bolt through the plate. They are tested by being bolted to a solid steel plate rather than to rock.

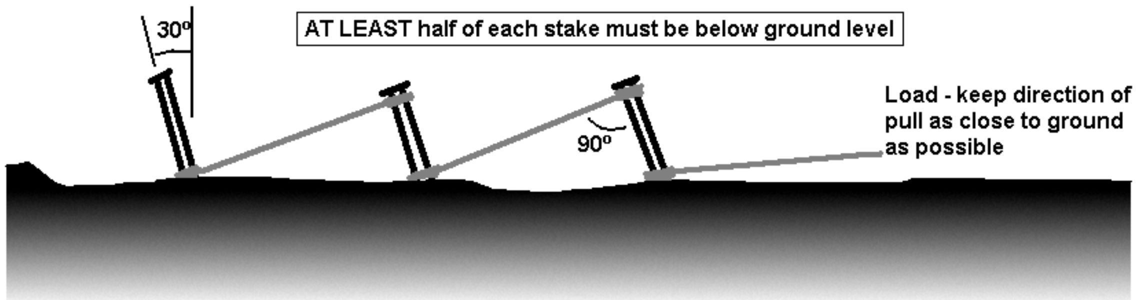
NOTE: Under EN795 it is a requirement that all rock anchors be produced from stainless steel. For this reason all steel plated or alloy hangers, sleeves and studs cannot be CE marked.

5e. Ground belays, stakes and anything else

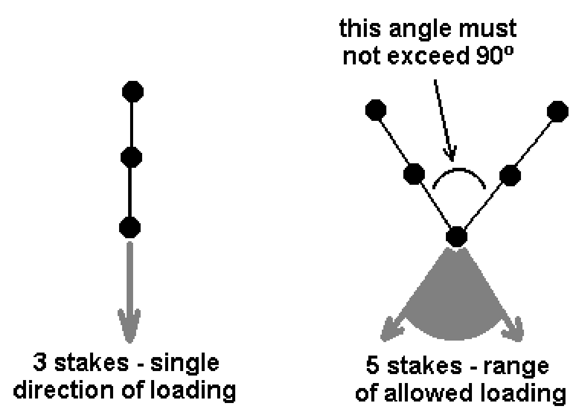
The notion of ground anchors in a cave may seem pointless, but your casualty must eventually make it to the surface, and teams are often asked to work on 'surface' incidents such as quarry faces where the great outdoors is your belay. If a landrover is to hand, it can make a very good anchor provided the part you clip into is welded to the rest of it. On 'normal' vehicles, avoid using the towing and lashing eyes, instead try and get a padded sling around an axle. It is amazing how you can improvise if you need to – on a shiny sportscar with no way of getting an 'underbody' anchor, wind down the windows and thread a sling through the inside, back round underneath the body and you have a bombproof belay.

An important point if you are putting your 4x4 into the anchor system is never, ever be tempted to use your vehicle winch or capstan as part of a hauling system – or even worse try driving the vehicle away to pull on a rope. The power of winches and moving vehicles cannot be controlled or sensed by the operators, and even a small winch has the power to snap your ropes and shatter your karabiners before you know what's happened.

Ground anchors come in various forms, some involve a steel plate with holes in it and a set of pins – the idea is to hammer the pins into the ground and literally 'nail' the plate to the earth. This has the disadvantage of placing all the stakes in a relatively small area of ground, risking choosing a bad bit. Classic stakes come in sets of three, and are rigged in a daisy chain as shown below. Each stake acts to hold the next one upright, preventing it from levering out of the ground.



Stakes must only be loaded in the direction of the chain – if your anchor must allow for a range of horizontal directions, then use **five** stakes arranged in a V-shape, but you must keep your range of loading within the angles made by the two sides of your V, as shown in the plan view on the right. If the angle subtended by your V-shape exceeds 90° then the strength of the anchor is seriously reduced when loaded in the central direction. When setting the stakes for a V-shape, the central stake should be angled to the mid-point of the V (vertically upwards in the diagram to the right).



5f. Rigging onto anchors

Having spent 20 minutes covering your pitch with slings, resin bolts, two landrovers and a team of horses, it now remains to connect your rigging to the stability of Mother Earth. This can be where all your planning and calculations go completely to pot, as you can very easily get this connection process very badly wrong. In the previous sections on each type of anchor we have highlighted the problems in loading and fitting (issues of direction, relative strength and so on) but now we have to use these, albeit correctly, to achieve what we want. More often than not your ideal rigging system will need anchors in places they don't exist, pulls in directions you aren't allowed and movement in places you can't fit. Such is the way of underground rigging, and this is why you are treated with such respect in the local drinking taverns.

I will assume that after reading this far, you are capable of using each type of anchor to it's limits and within safe practices. This section just gives you some points to consider when connecting them together:

1. A system must never rely on one anchor
2. Failing to a backup anchor should not introduce a shock load
3. Cross-loading backups is acceptable, but only in some situations
4. Load-sharing between anchors is no excuse for a set of crappy load limits
5. Think not of the way it is now, but what you will turn it into

Addressing these in turn:

1. Obvious, hopefully. Sometimes you really, really have no choice about it, but in those cases your redundant hauling system (two lines to the casualty, remember?) must go somewhere else, even if that somewhere else is far from ideal. There is only one exception to the single-anchor rule, that is where the anchor point is so goddamn solid that there is nothing you could possibly do to shift it, and you can make completely isolated connections to it. Example – a casually-placed house near to the shaft top. Not an example – a huge iron ring set into the base of a foundation. Why? 'Cos with the house you can wrap separate slings around it to keep the two systems totally independent. With your iron ring, it matters not if you use two krabs or two slings, if the ring snaps you lose the lot.
2. This is part of our 'no shock loading' rules from earlier chapters. When connecting your systems to the main anchor points you define the direction of loading, and so the direction of movement should that anchor fail. Your backup(s) should be placed in such a way that there is minimal slack in the connections in that direction – so your casualty does not have to free-fall 2 metres while a set of slings slap about wildly above them. Think y-hangs, self-equalising belays and deviations – it's better to use a weak deviation that is likely to pull out under load than none at all, as it will brake your casualty's free-fall.
3. Cross-loading means that you have less than the ideal 4 anchors, where two are the main tie-ins for your two hauling systems (A and B), and the others are backups. Suppose you only have two or three available – it is allowed to use the backup system B anchor as the main anchor for system A and vice-versa, provided that **every individual anchor is strong enough to support the entire system** in the event of a single failure. You must NEVER cross-load weak anchors, or you will risk something called the 'ripple effect', where failure of one shock-loads the next, which fails and shock-loads the third, and so on until gravity wins. A version of cross-loading which isn't always

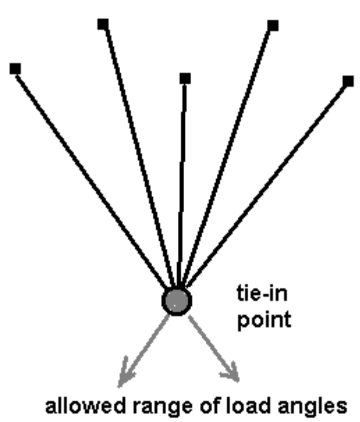
seen as such is the idea of using two anchors and two Y-hangs, as shown below. The same rules apply on using this method.

4. It is better to have one anchor that will resist a small nuclear blast than 20 that you can pull out like teeth, as under a shock-loading it's almost impossible to prevent unequal loading and the ripple effect. The caveat on this is deviations to a line of less than 45 degrees, where failure of the deviation is not dangerous to anyone. Some teams in the USA had an idea to *deliberately* set a system of weak anchors in front of the main belays, so that in a shock-loading they would ripple off and absorb the energy before the main belay saw the load. This is dangerously unpredictable and modern shock-absorbing belay equipment such as the Grigri or dynamic slings should be used. The problems they had were simple – you can end up with your load perched on a few remaining weak anchors in the ripple chain, and you have no idea when they will let go!
5. You rig your anchors carefully, looking at directions of pull and slack in Y-hangs and so on – but remember that when you load your system with 200kg, this will change dramatically. Also, unlike SRT rigging you will often change directions of pull and relative loadings as you use the system, so make sure that when you reach the pitch-head transfer all your backup belays don't suddenly develop 3 metres of slack rope! You often need to add extra anchors into the system that you can switch to as the use of your system changes, or rig variable-length links so you can change the loading across multiple connections.

At the end of this chapter we will introduce the idea of a 'releasable belay', but please remember that unclipping something during a hauling operation is never a simple decision! You may have decided that the item in question is in the way and not under load, but the guy getting onto the rope lower down the system may well argue that he needs it!

5f1. Anchor vectoring

Whenever you combine two anchors to a single tie-in point (TIP) there will be an angle between them. The smaller this angle, the smaller the load on each anchor when a centrally-positioned load is applied to your tie-in point, and the angle also defines your range of loading angle. If your load pulls outside the angle of your anchors, at least one connection will be slack, and in that case the anchor is not serving any purpose. If your load has a fixed direction, then minimising the angle between your anchors is the main aim. If you need a range of motion, then making sure your anchors stay loaded is a compromise against minimising the angles.

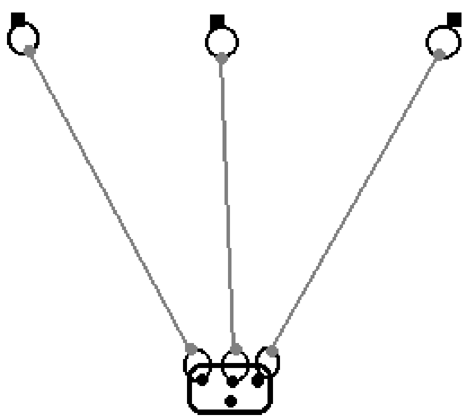


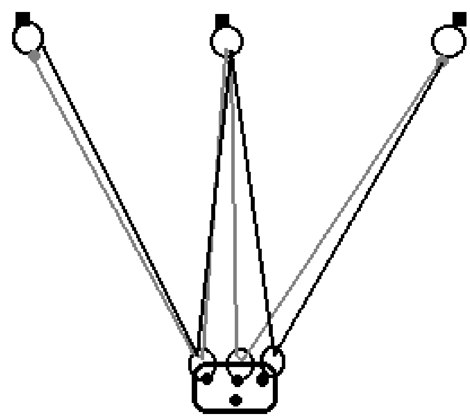
When you are faced with a set of anchors and a need for one tie-in point, there are two ways to go about interconnecting everything. The static approach says that you secure a fixed sling or rope from each anchor to the TIP, bringing them all together at a plate or collection of krabs. The length of each connection is adjusted to ensure all anchors are under the same tension. The dynamic approach says that you use a single long rope or sling and run back and forth from each anchor to the TIP, joining them together in a W-shape. As the rope slides back and forth it automatically adjusts the length of each section to keep all anchors under load.

The static approach has the disadvantage that the TIP becomes fixed in position, so that as your direction of load changes within your allowed range of angles, the load on each anchor varies. It has the advantage that if one anchor fails there will be no movement of the TIP, and the system will stay together.

In a dynamic system your range of load angles remains the same, but as you pull across the range the TIP moves with you, keeping each anchor under equal load. This can help if some anchors are weaker than others, but if the main interconnecting rope fails you can lose the entire setup. Also, if one anchor fails there is a large free-fall as the slack loop of rope is snapped back to each adjacent anchor point – which could in itself be catastrophic.

Which approach you take depends on the situation, but in general a static system is safer if an anchor is likely to fail and any fall-factor must be prevented. If you rig a dynamic system, you will need to arrange a separate backup belay to the TIP to cover the problems of anchor or rope failure, and that backup belay must of course allow for the movement of the TIP as your dynamic system reacts to changes in pull direction. The commonest way of achieving this is to rig the dynamic belay using two ropes running in parallel to guard against rope failure, and to rig a separate belay to the TIP to deal with the free-fall effect of losing one anchor. It can all get a bit messy, so often a static rig is simpler to live with and faster to construct.





5g. Belays for rescue

In this book we used the term ‘belaying’ for the very specific activity of protecting a live load from a fall using some dynamic friction device and a safety rope. Other books can use the term to mean ‘attaching something to an anchor’ or ‘raising or lowering a load’. For this book, and this section, a belay is something that is never under any load unless it is needed. It is never needed unless something else fails.

Section 7b discusses the use of backups and safety lines in detail, here we are addressing the belaying devices themselves. For now we will accept the simple premise from 7b that any live load (a person) that could suffer injury should one item of equipment fail must have a safety line and belay. In rescue this applies to almost all ropework, in sport caving it is most commonly seen as the safety line for a ladder-climber. Sport cavers using SRT dispense with the safety line, though industrial access workers retain it.

Before we start with the other points, let me get the first and most important one out of the way.

Never, ever let the rescuer become part of the belay system.

This is an absolutely vital rule, derives from our Sudden Death Rule and must never be broken. What it means is that the connection between the safety line and the anchors must not include a rescuer. Suppose a safety line was being belayed by a man with a Grigri. He clips the Grigri to his harness maillon and clips his two cowstails to the rock bolts beside him. Happy that he can work the Grigri in the ‘normal’ position and that he cannot be pulled off his stance, he works away. Then the hauling lines fail, and 250kg of casualty and stretcher arrive on his harness. Apart from risking damage to his cowstails (which were never designed to take that loading) there is no way on earth that he can get himself out of the system. His harness, the Grigri, cowstails and the casualty are locked together by 250kg of tension. Apart from the risk of failure, he is now unable to help with the failure that led to all this, and in effect now needs rescuing himself.

Far better would be to attach the belay device directly to the rock bolts (with a few short slings) and then to clip a cowstail to the bolts as an independent safety line for him. Should the casualty fall he can then lock off the Grigri and race over to help the rest of the team deal with whatever is left of the hauling system.

5h. Belaying equipment

There are countless techniques and sets of equipment for belaying a load, ranging from simple knots such as the HMS to complex self-acting devices such as the Grigri. The problem facing rescue riggers is that, without exception, these techniques and devices were intended to deal with normal sport climbing loads (70kg) and not a hurtling 200kg blob of stretcher-encased caver. What happens in that case can be unpredictable and quite terrifying. Devices can literally explode, ropes can be cut, auto-stop systems fail to do so and release systems don’t. As we have said throughout this book the deadlock comes from manufacturers not publishing test data for 200kg loads, lest someone take that as a legal licence to use equipment outside its design envelope. We must rely on tests performed by rescue teams, magazines and clubs. Inevitably this raises issues of accuracy, cross-comparison of techniques and the scarcity of tests simply due to the fact that to do them properly costs money. Few rescue teams can afford to destroy a set of belay devices, a coil or rope and a hank of karabiners in the name of ‘science’. You can tell the point by now – someone at a national level needs to arrange a properly-funded wide-ranging test programme, akin to the Lyon/HSE research but with rescue loads. Until that time rescue teams are literally waiting for an accident to happen in order to learn the limits of their equipment. – not a thought that makes us sleep soundly.

The data that follows is primarily taken from the work conducted by Technical Rescue magazine in 1996 plus tests conducted on an unofficial basis by several UK teams and the BCCTR. The results of the tests are given for information only. The passing of a test is not to be taken as approval of any device or technique for rescue loading.

In the strict legal sense you will always be working beyond the envelope of the devices in your system, what matters on the bottom line is not if they are certified but if they will fail.

I have combined the other test results into the same format as the TRM data, namely that a 200kg mass is dropped from varying positions and the pass/fail criteria is that the rope should not break, or slip more than 130cm. The peak anchor loading must not exceed 12kN, which is our anchor limit from Chapter 1. Often a device will 'pass' but will damage the rope so that it could not be used a second time. Since belay devices are fall arrest rather than lowering systems I define that such damage will not constitute a fail.

Rope types

We concentrate on semi-static 11mm rope for these tests, though where devices show a marked difference for dynamic rope we include the data as a comment. The tests have been forced to use clean dry rope, I have extrapolated theoretical results for wet and muddy rope based on comparisons done by the author.

Manual methods

These require an action on the part of a rescuer to hold and control the fall. This contravenes our Sudden Death Rule but we include the data as it is common to see these techniques in use. Maybe this section will convince you to change that.

A '0cm drop' is a release that shock-loads by only the stretch in the rope. A 'static load' is gently lowered onto the device to prevent any dynamic loads at all. Remember the load is 200kg.

Device	Static load	0cm drop	FF 0.33
Figure-8 descender	Fail	Fail	Fail
HMS hitch	Held, no slip	Fail	Fail
DMM Bettabrake	Held, no slip	Held, 20cm slip	Fail
5-bar alloy rack	Held, 20cm slip	Fail	Fail

Results for dynamic rope were similar. 'Fail' in all the above cases meant that the load could not be arrested within the 130cm limit. For most, arresting within *any* limit would be doubtful.

The implication is clear – a manual device cannot be expected to control any size of fall with a rescue load.

Automatic devices

An 'automatic' device in this section is one that, by a mechanical action of camming or compression, attempts to arrest rope travel through friction, known in this book as a PACD (positive action camming device). There is one incredibly important point to make:

> Rope clamps (ascenders) with toothed cams are not suitable for belaying

Anything with a toothed cam latches into the rope sheath and arrests motion by **weave insertion** rather than **friction**. This means there is no room for the rope to travel as the dynamic forces are absorbed, and the results for 200kg drop-tests are always that the rope is cut by the teeth. The same applies to pulley/clamp combination devices such as the Petzl Traxion series.

The following table is based on 11mm rope, a 200kg load and a fall factor of 0.33, the peak loading column is the average from the referenced tests.

Device	Pass/fail	Peak load kN	Comments
Petzl Shunt	FAIL	3.1	Failed to arrest motion
Petzl Stop*	FAIL	10.2	Rope severed at camming point
Petzl Grigri	PASS	8.5	Slippage ~75cm, release system jammed
SRT DB2	PASS	8.0	Slippage ~75cm, release arm jammed
Petzl Rescuecender	PASS	7.9	Slippage ~50cm, could not release
Double prusik**	PASS	8.6	Slippage ~50cm, could not release
Petzl I'D 1	PASS	6.6	Slippage ~75cm, release arm worked

*The Stop passed with 11mm dynamic rope, peak load 6.6kN and 25cm slippage.
** 8mm static cord, 3 wraps, classic prusik knot and 10cm spacing between each knot.

The I'D (type 1, the smaller of the two) is the only device tested that held a fall and could also be released after loading. For this reason alone it is the device suggested for all rescue belaying, followed by the Grigri or Rescuecender. The only difficulty with the I'D is a moderately complex method of operation, so team members need to be trained. 'I'D' stands for 'Industrial Descender' and unlike the Stop or Grigri you can stare at one for a long time and still not know how it works, so you may decide your team wants to go with 'simple and obvious'.

On clean wet ropes I expect the same results but with more slippage (almost double), though from our tests the pass for the Grigri/DB2/I'D may be borderline due to our slipping limit. For muddy ropes (fine clay sediment) the peak loads will drop by about 30%, the slippage will extend by about 50% but the Rescuecender and prusik should show less increase than the other devices as their camming surfaces are not completely smooth.

For the rest of this book I will revert to the Grigri/Rescuecender options simply because these are far more common in team kits at this time. Swapping to an I'D is a trivial matter should your team acquire them.

5i. Releasable belays

In later chapters on hauling systems, we will place great store by the releasable belay (RB). In simple terms, this is a variable-length connection from an anchor to your system, usually allowing you to lengthen it under load when you need to change the way things are hanging.

There are just as many ways of making an RB as there are of rigging a hauling system, but the notion of an RB is a simple thing that gets used once, so making it simple in itself is sensible. The two options are therefore:

1. A short rope running through a descender or grigri
2. A short rope with a tied-off friction knot

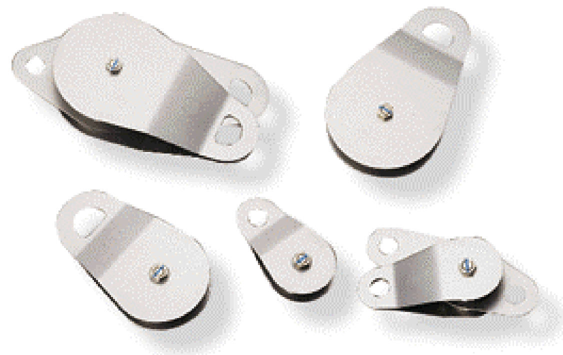
If you have a spare descender, then option 1 is the simplest as it can be re-set relatively easily. Connect the descender to the anchor point, run a short (static!) rope to the system tie-in point (STIP) and lock off your device. Only ever put the descender at the STIP if you can be sure that you will have access to it no matter how much rope you pay out!

Using a tied-off friction knot such as an Italian hitch is the other option – but remember that these knots are difficult to pay out when under a 200kg load. One way around this is to take several turns of the rope from the anchor to the STIP and back again, making a big compound pulley block before tying off to the hitch. This is safe since we are only using this once, so we can forget the rope-next-to-rope rubbing. The only problem with using a knot-based RB is that it's possible for the end of the rope to sail through the hitch if you let go under load. With a device-based RB, a stopper knot can prevent that.

Some teams use thinner accessory cord for making RBs, but since we will expect them to support full loads I expect them to be made of the same static rope as the rest of your kit! It is however worth keeping a set of short (5m to 10m) lengths of rope ready for making RBs. Some posh teams even keep them in dinky little bags so the spare rope can be kept tidily hung up next to the anchor until it's needed!

Rigging with RBs demands you keep a weather eye on loading on other anchors – as you release your RB do you change the loading on your main lines? Are your safety lines in need of RBs as well, and must they be paid out at the same time? Finally, if you lose the plot and pay out too much on your RB, have you backed yourself into an impossible situation? Yes? Read chapter 8 on jiggers!

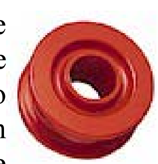
6. Pulleys



A pulley is, in essence, a device for letting a rope change direction with minimal friction. In rescue pulleys a wheel (called a sheave) spins on a metal axle, with one or more sealed bearings to reduce friction. In caving there are three basic patterns for pulleys – fixed, swingcheek and bobbin. Industrially there are thousands of pulleys available though we shall concentrate on those specifically intended for use within rescue ropework. Using a pulley from some other application, for example wire rope winches or marine rigging, is a recipe for disaster. Legally these pulleys would not be rated for use in rescue systems where a 'live' load is used, and often they are unsuitable for use with kernmantel static rope. It is important, for maximum strength and care of the rope, that the U-shaped groove in the sheave is the same diameter as the rope. Also, the pulley wheel must be smooth and should not impart oil or grease to the rope.

For use within the UK, all pulleys should comply with EN12278.

6a. Types of pulley



Bobbin pulleys are simply isolated pulley wheels, usually made of plastic, that are designed to clip into a karabiner to reduce friction of a rope passing over the karabiner itself. These are low-strength objects and of course it is very difficult to retain the rope on the wheel unless there is permanent tension in the rope. Bobbin pulleys have a place in personal caving equipment as emergency self-rescue devices or for hauling heavy tackle bags when sport caving. They do not have any place in rescue work and should not appear in any kit bag.

Fixed pulleys are comparatively rare, with the only common example used in the UK being the Petzl Fixe (P05) as shown to the right. Other pulleys of this design include the Kong Heavy Duty and Light Roll. Fixed pulleys have a rigid U-shaped alloy block that holds a sealed-bearing sheave and presents two side-by-side attachment holes. These are separated by enough distance to pass a rope into the block, and once a karabiner is placed through the two holes the rope is secured in position. Fixed pulleys have a unique method for connecting two karabiners to the pulley, since the mounting holes are usually only large enough for one. We discuss the Fixe and its use in rescue in the A-block and Z-rig sections that follow.

There is a tandem version of the Fixe as shown to the left. This is specifically designed for use on traverses and should never be used in a conventional pulley system. Petzl show it's use in compound pulley blocks, however it is not rescue-load rated.

The most common rescue pulleys are all **swingcheek design**. Here each side of the pulley block is secured to the axis but is free to rotate. Thus, these 'cheeks' can be swung open to allow connection of a rope, and then they are secured together by the action of connecting a karabiner through the attachment hole in each. Large swingcheek pulleys all have sealed bearings, and many are available in twin or triple sheave models. Examples include the Petzl Rescue P50 Kong Extra Roll / Swing Roll and the SMC rescue models.

Many suppliers describe some pulleys as 'prusik-minding'. These have a squared-off shape to the cheeks as shown to the right, and are designed to catch a prusik knot against the edge of the cheeks, since using a prusik knot as a 1-way device is common in the USA.

Many pulleys, especially twin or triple swingcheek designs, have an extra mounting hole opposite the main attachment point and usually made in the central dividing plate between the sheaves on multi-sheave pulleys. This hole is called a 'becket' and is intended as a point to tie off the end of a rope when you are constructing compound pulley systems. It has very little other purpose and should never be used as an anchor for another part of the system (such as a belay device). Often the becket rated strength is less than that of the top hole.

At this point it is important to mention lightweight pulleys. These are specifically intended for personal use (self-rescue or gear hauling) and are totally unsuitable for rescue work. Examples include the Petzl Oscillante P02 (rated at only 9kN). It is important that these pulleys should not be found in rescue kit bags, or at some point someone will be tempted to use one. The same applies to bobbin pulleys as they offer limited benefit and are highly unreliable in use unless tended lovingly at all times.

One final pulley variant to note is the knot-passing pulley. These have an extra-wide sheave and are designed to allow some inline knots (such as the DF) to pass through the pulley. The most common example in the UK is the Petzl Kootenay as shown to the left. These have a specific application to running long traverses or for hauling objects other than rope (such as hoses or air lines) but should NEVER be used with two ropes passing over the sheave in parallel. You may at some point need to move one rope with respect to the other, and the rope-on-rope rub point you will create could be catastrophic..

6b. Choosing pulleys for rescue

Choosing between models is a matter of cost and availability as well as strength. However at this point I must make an important statement about the rule on strength and the exceptions to the rule. For common rescue applications of deviating a rope then pulleys must be rated at full rescue loading as we shall describe below. However for the **specific application of an A-block** as discussed in Section 8a, pulleys of lower strength can be used. This is contradictory to the general rules on not including weaker components in rescue kits, however in the case of the A-block there is a valid reason. Inclusion of a rope clamp into the A-block results in a very low working strength, defined by the teeth of the clamp. Typically this is only 4kN, therefore it can be argued that a pulley need not be rated to a significantly greater strength. We will discuss this in detail in Section 8a, however it is this reason that allows us to include the Petzl Fixe pulley in our approved lists. This pulley is not rated for a full rescue load, however is specifically designed for making A-blocks and is it difficult to find a better alternative.

To clarify therefore we have two general uses for pulleys within this book:

1. General pulleys as used for deviating ropes, for example at pitch heads, surface tripods or for counterbalance systems. Also used for running on tyrolean traverses.
2. A-block pulleys, specifically intended for the sole use of forming A-blocks as described in Section 8a of this book.

We shall show in Section 8a that most models of general-purpose pulley are not suitable for fashioning A-blocks, and equally A-block pulleys may not be strong enough for some of the more extreme applications of general rescue pulleys. The motto of knowing your equipment is paramount!

6b1. General pulleys for a full rescue load

For rescue hauling a minimum working strength per side of 15kN is essential (thus a rated strength of the mounting point of 30kN). Most rescue pulleys provide this with ease, though some are stronger than others. The Petzl P50 is rated at 16+16kN, whereas the Kong Heavy Duty is rated at 25+25kN. As well as strength, pulleys used in rescue must be compatible with the ropes used (i.e. have a maximum capacity greater than 11mm) and should offer good points of attachment. The use of double-sheave or becketed pulleys is a matter of rigging, though in UK cave rescue neither are vital and their inclusion in kits is a team decision.
As we shall see when constructing hauling systems, it is often important to connect more than one karabiner into the pulley. Some rescue pulleys, such as the SMC models, have holes only large enough for one krab, and so is not an advisable part of the kit when multiple-capacity pulleys of the same strength and price are available.

Motto: avoid equipment that is limited by design from being used in common tasks.

6c. Minder slings

Often a pulley failure will lead to a significant fall on the main lines. In systems such as the Z-rig a main pulley failure could be catastrophic. Whilst rescue pulleys are designed for strength and rarely fail, you are in effect relying on the single pulley axis as the sole point of support. It is not ideal in rescue rigging to have a possible catastrophe without some redundant backup. Pulleys have failed in the past and the results have on occasion been unpleasant.

The simplest solution is to install a ‘minder sling’ – simply a karabiner clipped into the line on one side of the pulley and attached by a sling or dynamic rope loop to a pair of anchors. Ideally these should be separate from those supporting the pulley, but caves are never ideal. Even using the same anchors you will protect against pulley failure itself. Of prime importance is that the possible fall factor is minimised – so the sling should be as short as possible whilst not coming under direct tension.

As we have said in our anchoring chapter if you are running twin ropes (a main and backup, or two hauling lines) then it is acceptable in the absence of any other anchors to cross-load your backups – connecting the minder sling from line 1 into the anchors of line 2 and vice versa.

6d. Pulley mechanics

Using a pulley (or anything else that deviates a rope) will of course involve applying force to the rope. Pulleys therefore experience loadings, but some fail to realise that in some cases that loading can be up to twice the force in the main lines. When hauling against a load the force on the pulley can even exceed this value. Clearly given that rescue loads are large to start with, this can place an extremely high demand on the pulley itself, connecting hardware and the anchors. Connecting a 50kN pulley to a single 10kN rock anchor is not going to somehow force the rock to grip harder…

In the later chapter on vectors and forces we will show the mathematics behind these forces and how to calculate them using only a patch of mud and a fingertip. Before then however we can reveal the three simplest cases. Assuming here that the rope is not moving and that a load of F is applied to each end (the load must be equal as the pulley would rotate if it were not):

A 60° bend will create a force on the pulley anchor of F
A 90° bend will create a force on the pulley anchor of 1.4F
A 180° bend will create a force on the pulley anchor of 2F

Many rescue riggers know this and try if at all possible to stick to 60° bends. In caves however, ropes must follow what nature has excavated. Often at a pitch head angles greater than 90 degrees are common, and certainly within hauling systems such as the Z-rig or for surface tripods 180° bends are the norm. Anchors, karabiners and slings must all be chosen with this in mind. My suggested policy is:

- Use only rescue pulleys of 15+15=30kN minimum strength with the exception of the specific application to A-blocks, as detailed in Section 8a.
- If the pulley is anchored by a single karabiner it must be rated to 45kN.
- If two separate karabiners are used these can be 25kN or ideally 30kN.
- Maillon rapides should not be used to connect into a pulley, indeed often the swingcheek width and method of closing will make passing of a maillon difficult due to the small gate opening and narrow gap between the gate and spine.
- A minimum of two suitable anchors must be used for any pulley angle of 90 degrees or above. The total distributed strength of the anchors must be greater than 40kN (so two 25kN resin P-hangers are ideal).
- Wherever failure of a pulley would lead to a significant fall a minder sling should be used.

6e. Dynamic friction and edge effects

This section goes beyond pulleys so that comparisons can be drawn and as such will be referred to elsewhere in this book.

When a rope runs through a pulley, over and edge or through a mechanical device and nothing is moving then the simple maths above works fine. What many fail to realise is that when you are pulling a rope through a pulley the idea of 1+1=2 no longer quite works!

To clarify, an ‘edge’ is something that the rope deviates over, such as a scaffolding pole, wooden beam or similar. A device in this section refers to a mechanical ascender or descender in the non-locked mode where the rope can run through the device freely.

All pulleys, devices and edges have a friction factor (which I will denote β to avoid confusion with fall factor). This is the ratio of forces in the two sides of the rope when the rope is moving, and is a measure of the friction. The value of β depends on many factors and is difficult to predict with accuracy, but the most important influences are the object itself and the angle through which the rope deviates. A larger angle means that (in general) more of the rope is in contact with the object and so the friction is higher. For pulleys however this does not apply, as the rope itself does not move with respect to the sheave. The contact between the sheave and bearing is fixed, so **the value of β for a pulley is constant with deviation angle**. Of course other factors such as mud, water or extremes of temperature can change β dramatically.
For rescue pulleys having a value of $\beta<1.3$ then the effects can be neglected in common rigging. All other devices with $\beta>1.3$ must be thought through carefully as a rigging system is being installed, or you may find the forces on anchors or karabiners escalate to the failure point very quickly!

As we have said the type of rope (how stiff it is and issues of wet vs. dry), the presence of mud and general wear and tear can change β dramatically. To give an idea of the values you may find here are the results of measurements by the author, based on lifting a 100kg mass using relatively new 11mm semi-static rope in clean dry conditions.

Details of edge	**β (90° deviation)**	**β (180° deviation)**
Perfect friction-free edge	1.0	1.0
25mm diameter smooth aluminium tube*	1.8	2.2
50mm diameter smooth aluminium tube*	1.7	2.1
50mm diameter smooth nylon tube*	1.5	2.0
20mm diameter smooth nylon tube*	1.7	2.1
90° corner of clean limestone (10mm radius)	2.0	-
90° corner of planed timber (sharp edge)	2.9	-
25kN aluminium karabiner	2.2	2.3
Petzl P05 Fixe pulley	1.5	1.5
Petzl Rescue P50 pulley	1.1	1.1
Petzl Pro Traxion P51 self-jamming pulley	-	1.1
7mm steel maillon rapide	2.2	3.0
Petzl Grigri (rigged normally)+	-	3.2
Petzl Stop (rigged for belaying)+	-	4.0

* Fixed so as not to rotate as the rope moves.
+ Rope is being raised, therefore pulling through these devices in the non-locking direction.

As expected pulleys perform best, and rescue pulleys top the list. A single karabiner or fixed 50mm-diameter scaffolding tube can roughly be expected to double to force and a maillon rapide to triple it, the higher value resulting from the smaller bend radius. Then come surprisingly high values for the Grigri and Stop. Even with the Stop rigged for belaying (using the bottom cam only) the steady-pull β is very large indeed. The Grigri is particularly disappointing as it is otherwise a good all-round performer. In both cases of course the friction is the result of the rope running around a fixed grooved cam, giving a very large contact area. Both devices rely on this high friction to operate – it is the force that allows the auto-locking process to work. For hauling however it is a serious problem.

6f. Peak forces

When hauling by hand at a steady speed the forces generated over a friction component are given above. However when hauling takes place in bursts the peak forces are higher, as you are expending energy to accelerate the load as well as move it. The average loading over time of course remains the same no matter how you pull, but of concern for anchor loading is the peak force during the first seconds of each pull. The exact peak force depends on the precise speed and style of hauling but tests conducted by the author and others have shown that for a human pull (as would be found in rescue) where each movement takes in about 1m of rope and lasts about 3 seconds from stop to stop, the peak forces for all types of friction edge are about 1.3 times the steady force. For safety, therefore, we shall define the peak force as 1.5x the steady load under motion.

Therefore: **Peak load in a tail rope = lifted weight x β x 1.5**

Remember also that you must allow for the addition of forces caused by the angles between the ropes! This means that the load you experience on an anchor can be very different from what you expect to get! Let's see some examples:

e.g. 100kg mass lifted over 180° bend using a P50 rescue pulley:

Firstly, the tail and load are at 180° so the static load on the anchor is 2 x 100kg. However, when in motion the forces are not equal anymore (due to β). On the load side we have the basic 100kg mass, we'll allow a factor of 1.5 to account for the extra force we are putting in to accelerate it, so the peak load on one side is 1.5kN.

On the other side (the tail) we are hauling in the 1oad of 100kg and allowing our 1.5 factor for peak effort, but we must include the effect of β – so the peak force on the tail side is:

peak load = 1000 x 1.1 x 1.5 = 1650N

Since the two forces are parallel, the effect at the anchor is additive, so the peak anchor load is 1.5 + 1.65 = 3.15kN (equivalent to a static mass of 315kg).

e.g.2 100kg mass lifted over 180° bend using a Petzl Stop in belay mode:

Again, the load side peak force is 1.5 x 1kN = 1.5kN, but the value of β is now 4.0 from the table above, so the peak load on the hauling side is 6kN! As hauling and load forces are approximately parallel again, they are additive:

The resulting anchor load is a massive 7.5kN (equivalent to a 750kg static mass)

These represent probably the best and worst cases, and as you can see even in the best solution the anchor load is significantly higher than the lifted weight. At the other end of the spectrum the humble Stop can create anchor loads of many times the lifted weight. Whilst 7.5kN is not large compared to the strengths of anchors and karabiners we will be using, it happens to exceed the 5kN rated test strength of the Stop itself. As we may on occasion try to lift a full rescue load of 200kg only the foolhardy would rely on the ability of a device to work correctly at over twice the test limit. This is a clear example that for rescue rigging we can easily push devices beyond their designed limits, often without realising it.

So how do we deal with heavy loads and yet avoid battling against these issues of high friction and relatively weak components? The solution is to adopt compound pulley systems that both reduce the end-point forces needed and distribute the loads reliably. This is the subject of the next three chapters.

This is the end of section 1
This file last updated: 11 May 2003

Changes from last issue: Updated reasons behind rescue load in Ch1, minor tinkering with contents list and page breaks. Nothing significant!

Life on a line

Part Two

A manual of modern cave rescue ropework techniques

Dr. D. F. Merchant

Published online at draftlight.net/lifeonaline issue 1.2

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The book is published in three parts, as divided below. This is part 2. It should not be read or republished in isolation from the other parts, to which important references are made.

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IMPORTANT NOTE

This is part two of a three-part publication. The material within this part is subject to the disclaimers of liability, intent and suitability as given in part 1. This part is not to be used in isolation and without reference to parts 1 or 3.

7. Basic hauling

We have defined 'hauling' as a process of raising a load under controlled conditions, using ropework, winches and manpower. This chapter introduces the basic ideas, and simple techniques to follow before Chapter 8 deals with the specific systems and equipment used.

7a. Introduction

Hauling has to follow a few ground rules in order for us to deal with it predictably. The prime rule, which I shall mention over and over, is that a hauling system is not intended to receive any significant shock loading. The lines should be in tension at all times the load is present, therefore apart from equipment failure the load simply has no ability to fall any distance while still fixed to the lines. This rule allows us to design systems that are efficient, rapid and simple to operate and yet may not be capable of dealing with a full 200kg shock-loading incident. It then becomes the responsibility of the pitch rigger to ensure that a shock loading cannot occur and that safety backups are used wherever a single equipment failure incident could lead to one. It could be argued that for ultimate safety all hauling systems must be capable of surviving our full 200kg / FF0.3 rescue fall, but unfortunately the vast majority of available ropework equipment used in hauling systems cannot meet this. We instead take the philosophy of forbidding a fall, then designing out the risk of one by using backup devices. There naturally remains a very small risk of a double- or triple-failure allowing a fall to escape through our designs, but the same applies to every other aspect of ropework. There are those that argue we should battle on to remove any risk, no matter how miraculous the chain of events needed to cause it – but then they probably don't use passenger planes either!

In sections 5g/5h we discuss belay systems, and I should stress that a hauling system and a belay system are separate creatures for separate tasks. Belay systems are designed to react to and survive a shock loading, plus offer the ability to perform a 'routine' controlled lower. Hauling systems allow controlled raising of a load with some possibility of a controlled lower, but shock loading is not an option. The equipment, rigging and operation of belay and hauling systems is different and in many cases it is not even that easy to convert one into another. Having said that, at a pitch head you will probably end up with a hauling system and belay system side-by-side as belay systems are used in backup – so those operating them must know the differences – which lines should be in tension more than others, which lines are released first and so on.

7b. Backups and safety lines

To ensure that our system designs out the possibility of a shock load it must allow for the failure of any one item of equipment without introducing such a load. This is a protocol called single-redundancy and is the usual standard of safety applied to underground rescue. Double-redundancy (where any two unrelated failures could occur without causing a shock load) is possible to apply in high-risk situations but for the general cave rescue scenario the complexity, rigging time and operator skill issues overrule it. A single-redundancy system requires two failures before catastrophe, and so far in UK cave rescue this has never occurred.

This section is titled ‘backups and safety lines’ as there is a distinction between them. A ‘backup’ is an additional set of equipment (ropes, pulleys, etc.) designed to immediately and automatically replace a failed primary system and it *should leave the hauling system fully operational*. A ‘safety line’ is designed to prevent catastrophe (holding a falling load, etc) but does *not* have to preserve the operation of the system.

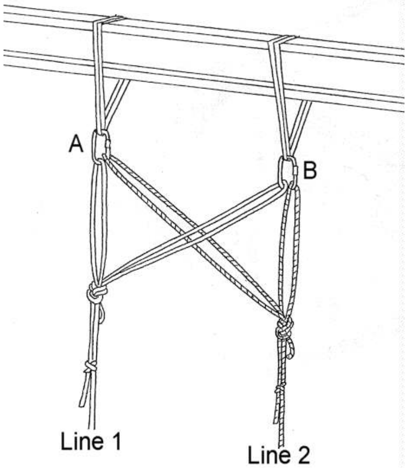
As an example of this subtle difference, a double anchor for a pulley is a backup, as failure of one anchor would not significantly affect the pulley and what it was used for. A belay line on a caver ascending a ladder is a safety line, as if the ladder (the primary system) fails then the caver is saved from injury but is not able to proceed upwards.

In an ideal world we would therefore like backups in preference to safety lines, but the underground rescue environment is far from ideal. In many cases (such as the ladder example above) then there is a theoretical way of creating a backup (caver wears full SRT kit so can climb the safety line, or there are two ladders fitted side-by-side) but the complexity outweighs the (small) risks. This argument is making a strong point: if something is *likely* to fail it should be a fully operational backup. Safety lines are for situations where failure is rare.

In industrial access work, the use of redundancy is strictly controlled and always required. Rules are laid down over the use of anchors, which types of ropes to use and how to arrange rescue systems in the event of a primary failure. Underground rescue demands a more flexible system, yet safety cannot be compromised by flexibility. One or two ‘industrial’ rules can therefore be kept:

1. When a load reverts to a backup after a primary failure, the fall factor and shock loading must be minimised.
2. Backups must not use the same anchors as the primary system they are protecting, but may share the primary anchors of an independent system.
3. Backups must be designed so that the load can be transferred to a place of safety without alteration of the rigging should the primary system be inoperable

(1) requires us to make sure that backup lines are always taken in or paid out with minimal slack, that anchor backups and slings are the correct length and not lying about in coils, and that a change of load from primary to backup will not swing the load across a pitch and into the wall like a bottle against a ship.
(2) can cause problems underground, where anchors are sometimes limited. Industrially you can always spend time adding anchors, underground you cannot. Your backup system must *never* share the same anchors as the system it protects (otherwise what would happen if those anchors were the point of failure?) but usually underground you can use primary anchors from an unrelated system (a technique called cross-loading, as introduced in section 5f). For example, you have a hauling system in a shaft, and a ladder-and-lifeline system alongside it for rescuers. You are allowed to connect the lifeline to the same anchors as the hauling system, or to connect the hauling system backup line to the same anchors as either the ladder or the lifeline. Failure of any one of the 4 systems will not cause total failure of the other 3. There is a problem when you are using a full twin-rope system (double-redundancy, with two main lines and two backups) as it is *permissible* to cross-load the 4 systems onto two anchors but if the 4-rope system is being used because failure is very likely, then you may wish to have as many independent anchors as you can get for the same reason!
(3) is important in rescue as more often than not your ‘load’ is an injured casualty and leaving them hanging on a backup line is not an option. If a failure leads to the primary system not



being operational (example: ladder and lifeline scenario, ladder fails) then whatever belay equipment you use on the lifeline must allow you to (at the very least) lower the load to the foot of the pitch safely and quickly. This, by the way, is one argument against using prusik knots for belays as opposed to mechanical devices – they can lock onto the rope and prevent subsequent lowering to safety.

The diagram to the left shows a typical arrangement of ‘cross-loading’. Two main lines are rigged from two anchor points. For line 1, anchor A is the main load-bearing point and anchor B is the backup. For line 2, B is the main point and A is the backup. With this arrangement, loss of one anchor will not fail either of the ropes, though of course the obvious question in this diagram should be ‘why not put 4 slings on that damn great RSJ and just make it properly redundant?’

7b1. Primary lines as backups

Using the definition of ‘backup’ as a way of recovering an operational system in the event of a primary failure, then there is no reason why the backup system cannot simply be a redundant part of the primary system. The best example is the traverse – if you use two ropes to rig the traverse, each under identical tension, then both are acting as primary lines but also both are backups in the event of one rope snapping. Industrially this is common practice but underground the use of a full twinned system (two identical primary systems acting in tandem) is not very common, despite advantages. Putting it simply, if your backup system must preserve an operational system then it must be (in most cases) a copy of the primary system in all but name. In that case, why not use it to reduce the load in the primary equipment and thus maybe prevent the failure in the first place?

The only problem with a fully twinned system (apart from the extra kit and time to rig it) is communication. At the casualty end of the rope it can be difficult to tell which line is from which system, so giving orders to rope handling teams can be tricky. The only reliable way around this is to use lines of two different colours (everyone understands ‘take in on yellow’) but getting coloured SRT rope is not easy in the UK. The other option is to label each system. I have worked quite successfully with teams by carrying a set of numbered plastic tags (a set of ‘1’s and a set of ‘2’s, which you slap onto the end of each rope and onto the hauling rig (plus anywhere else you’d need to know) so that ‘take in on 2’ makes sense to everyone.

7b2. Recovering redundancy

This is not a section on employer relations, but an important and often overlooked problem with all redundant safety systems. Once your primary system has failed and you are hanging on your backup you may well be able to continue the haul, but you are now out of options. Another failure will result in catastrophe. Once a primary system has failed the rigger must make a snap decision on the best option:

1. Continue the haul using the backup line and hope another failure doesn't happen
2. Stop all movement while another backup is rigged or the primary system is fixed
3. Lower the casualty back down to safety while the system is fixed

Which option you choose cannot be predicted in a book – it depends on the length of time it would take to complete the haul, how far up the casualty has got, where the dangerous points are and so on. The decision must also take account of the medical condition of the casualty and how quickly they must be extricated. The rigger is faced with a 'best of the worst' list of options but getting it wrong can be disastrous.

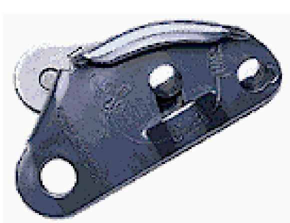
A final point that should, after all my nagging so far, not be needed: A backup is not an excuse for rigging a crappy primary system that is likely to shrivel and die when you breathe on it!

7c. Lowering

'Lowering' is often said, by those surface team types, to be something we never bother with as we haul casualties upwards. It's surprising, however, how much lowering can be needed on a rescue, even if the overall effect is getting them out and up! We do have the advantage that when you lower anything, gravity is on your side. However, the attraction between the planet and a casualty encased in medical equipment is surprisingly strong, so it's not just a case of letting them slither down through your fingers!

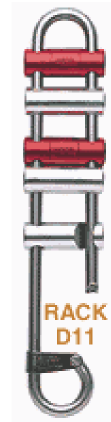
Before leaping off into lowering, I want to avoid backing myself into a literary loop by making this point – in almost all cave rescue work you may have to include the ability to lift a load while you are lowering it, and that demands a hauling system instead of a lowering one. So, a simple 'down-only' system is often quite rare. Rarity don't make it less useful though ☺

A bare-bones lowering system allows control over the movement of the line through a friction device, a safety line or twin main lines for redundancy and suitable anchors for everything. Most of this has been dealt with in the previous chapters with the exception of the friction device. In Section 5g we looked at devices for belaying, but made the point that a **belay device** is not the same as a **lowering device**. In belaying, the equipment should not be under load unless something goes awry, however in lowering it always is (unless something goes equally wrong, in which case you'll be glad of your safety line!). This means that certain devices are unsuitable for one application. Examples include:



The **Grigri** is ideal for belaying, but less suited to lowering as the friction control is too insensitive, making control of the load difficult. We will be using it to create Z-rigs in chapter 8, since it has become a common use in UK teams and has advantages that outweigh the problems in many cases. Remember however that Petzl certify the Grigri for single-man loading only, so any application to rescue brings in the great CE/PPE legal question.

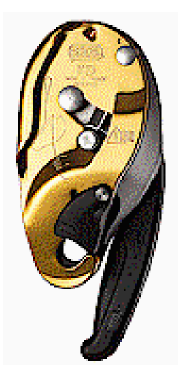
Descenders such as the **Petzl Stop** and **rack** can be suited to lowering, but aredifficult to use in dynamic belaying. The **Stop** can fail if rescue-loaded dynamically but has proven reliable in steady-force lowering despite weights being outside the approval envelope. As it is a mainstay of UK caving, teams often carry them simply for cost and familiarity reasons. I would suggest



that those are not the best reasons for selecting kit – better to train teams to use stronger equipment than give them something recognisable and flimsy! The **rack** falls foul of our failsafe rules unless a Shunt or prusik loop are used as a backup, but the prime issue over a rack is that there are no CE/EN/PPE standards relating to them. Whilst that does not mean they aren't suitable for their intended use, we are using them for something else that the manufacturer will be guaranteed to say is outside their test envelope, and without even a hint of a CE stamp your team are treading on a legal false floor. Many team members in the UK use a rack as part of their personal caving gear, and in the USA special rescue racks are in common use. Personally, some of these rescue racks are extremely well designed and work far better with extreme loads than some of the autolocking systems, however the CE marking issue creeps in.

It is however worth mentioning the **BMS nanobelay** at this point. Shown to the right, this has a handles and non-handled version, and looks basically like a 3-bar rack. It is however specifically designed as a lowering/belaying device and not for personal descent. The handled version allows the load to be released in a controlled manner. Despite not being CE marked (the device is produced for the US market) it has to be mentioned due to it's amazing performance. It will arrest a fall factor 1.0 drop of a 300kg load with a slip of less than a metre, and has a frame failure loading of 89 kN. This makes it far exceed any other commercial belay device in the world. With a failsafe backup on the tail line (such as a prusik loop) and CE approval, this device could be unbeatable.

<u>The I'D</u>



By far the best device for <u>lowering</u> in rescue is the Petzl I'D. It is failsafe, relatively easy to use and most importantly it has been tested at rescue loadings and proven to work, so far the only descender to do so. Given the questionable issues of liability, PPE and CE approvals rescue teams have to face (see Chapter 11) it should be part of every team kit as a matter of course, at least until someone else makes a cheaper, stronger and lighter version! However, it is relatively rare in UK teams at the moment and takes a bit of thought for those who've never used one. You can use the I'D for belaying and lowering, but I will reserve it from incorporation into hauling systems such as the Z-rig, since by design it has very high friction on take-in under load. In fact, the friction generated by an I'D is enough to make the mechanical advantage of the Z-rig less than 1! This is unfortunately an example of a piece of kit that is approved, strong, reliable but not good at everything – nothing new there then!

This is said without commercial bias – it is simply that the I'D passes the tests and very little else does. Maybe it's a point for other manufacturers to note! If the nanobelay had CE approval it would be a hard act to follow, but it doesn't, so the I'D seems to have things covered.

I'm going to sidestep here (hence the box) and deal with the notion of non-failsafe devices again. In Belaying we ruled out any device that failed to meet our Sudden Death Rule and needed attention to prevent uncontrolled release. In lowering, especially of equipment, it is often common practice to use friction knots (such as the HMS or a simple multi-turn wrap) which we suggested are unsuited to belaying. This is a clear exemption to the previous rule **provided that they include a backup** such as a prusik knot or rope clamp to lock the device should the attendant lose control. Lowering a live load on friction knots (or a non-failsafe device such as a rack) is permissible if:

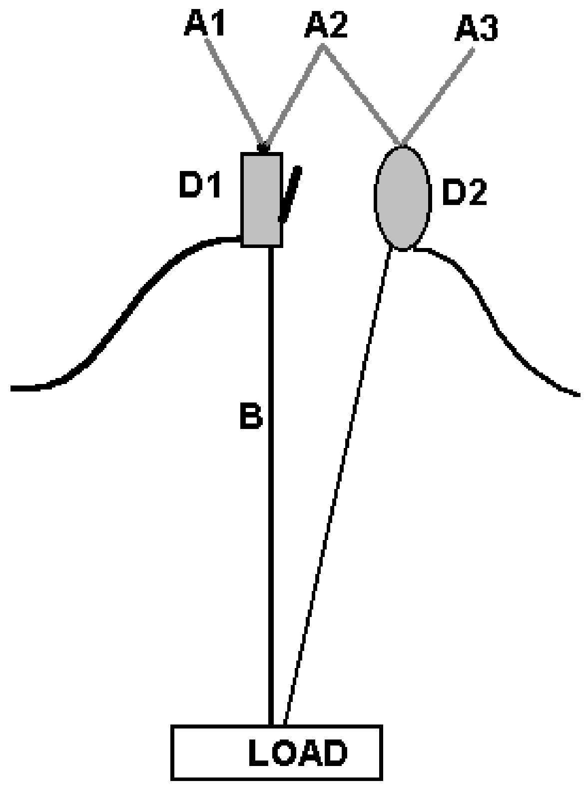
(a) there are no failsafe devices easily available to use instead
(b) a backup prusik knot or clamp is used
(c) There is equipment available to release the backup (such as a jigger, see Section 8e) if it becomes locked.

The most common friction knot seen in lowering, especially by surface teams, is the HMS. With a full rescue load a single HMS does not offer enough friction to control the lower using one man, so one useful trick is to run the tail rope from the first HMS knot into a second one, thus doubling the applied friction. This technique does however make it almost impossible to pull any line back in should the need arise, as the high friction works both ways!

Now, back to lowering rigs. Everyone should be thinking at this stage 'Ah, but it's easy – just clip a descender into an anchor and run the rope through it'. True, that bit IS the easy part. What your rescue-head should be thinking is how we include redundancy and deal with a descender that's liable to be very frisky with such a large load on it.

7c1. Basic lowering

A schematic lowering rig is shown to the right. Here the main line connects the load to descender D1, and a backup line connects it to D2, both of which I shall insist are I'D descenders. The three anchors are cross-loaded on A2 as permitted by our anchoring rules of chapter 5.



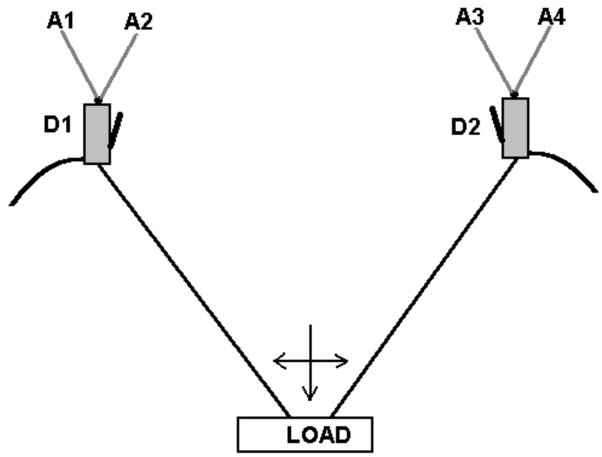
It could be suggested that we could add some kind of backup device to the main line at position B to protect against D1 blowing up, but (a) that is why we have the line and D2 rigged up next to it, and (b) any automatic rope-clamp device used at B will have to be manually held open during the lowering operation, consuming another rescuer.

During lowering, the line to D1 supports the load and the line to D2 should just be taut. It is very difficult to achieve this during a lower, as with two operators on D1 and D2 it is almost impossible to keep pace with each other. As a result, the load will shift between the lines, so at any one time either can be the 'main' line. This is not too critical provided that both D1 and D2 can operate as belay-safe lowering devices. After our discussions in chapter 5 we decided that only the I'D allows full lowering *and* the ability to survive small dynamic falls.

This is a major issue with lowering rescue loads – you cannot afford your backup line to develop any slack or you risk a dynamic loading situation your equipment may not be able to handle, and yet if you try to juggle the two lines in synch you risk passing the 'dynamic risk' to the other device. Motto? Both descenders and anchors must be the same! No good thinking 'Ah – I'll use an I'D on the backup and a Stop on the main line' if the exact moment of failure is the same exact moment when the load is held by the backup – remember the line under load is going to be the one to fail, so which one gets the weak descender then?

Some teams argue that by using a **dynamic** line for the backup you can control the load-sharing better (since it's easier to absorb distance inequalities if one line stretches) but we have ruled out dynamic lines on the grounds they extend too much under load. For a pitch where this is no problem, dynamic backups are fine. Find me such a pitch and I'll eat my hat – 'cos you can always fail the main line 2 feet above the floor with 3ft of dynamic bounce! Drop a spinal patient 2 feet and he will hurt you more than you hurt him. Having made this point there will be legions of riggers who will counter-attack saying that using a static line means you may be taking dynamic loads on a system that cannot absorb them, to which I reply that if you have a system with slack in it you're not looking after it properly ☺

7c2. V-lowering



One exception to this issue of load-synchronising (there is always an exception) is when you want it to occur. The only 'common' situation is a V-lower, where the load is suspended between two lines running to two control points some distance apart. This, as shown in the diagram, is a useful tool for landing a load onto a predetermined point between the control points when access directly above that point is not possible, and could perhaps be used to land someone on flat ground at the foot of a gorge, or onto a safe area within a rift or stope. In this situation carefully-controlled synchronised lowering by each station can control the horizontal *and* vertical position of the load within the limits of each station. The drawback is that you must treat the rig as a full V-rig (see Section 8b for a full discussion of V-rigs) and two backup lines need to be used, one to each station. If you rely on the two load-bearing lines, then failure of one will result in the painful 'champagne bottle and ship' procedure. Motto? Whenever there looks like there's a simple elegant fiddle, you can bet you're missing something complex and important.

Now that we have addressed lowering (which as we have said is rare in isolation) we shall move on to the rigs needed to *raise* a load. Most of these can also be used to lower it back down again, and in 99% of cases the initial motion desired is upwards in cave rescue, so what follows is the best place to start!

7d. 1:1 Armstrong hauling

'Armstrong' is an American term, but it's nicely apt, as to lift anything sensible by brute force, your arms had better be! In a vast series of tests it has been generally accepted that a fit adult male, given nothing but a rope over a cliff-edge and the power of his body (in any way he can think of using it) can only lift 50kg or less. Strong types may be able to raise 80kg by a few inches, but hauling a load up 30ft and you are strictly in the below-body-weight category. In the underground environment it gets even worse, as more often than not the direction of pull is sideways at a pitch head, limiting the force from each rescuer to only a few tens of kilos.

As with all seemingly-useless methods, 1:1 hauling does have a few applications. For a start, if you are lifting anything of 50kg or less (i.e. equipment) then it's far quicker to put a few people on the rope and pull than rig a mechanical advantage system so that one man can do it instead. The other useful situation is an assisted ascent of a surface shaft, where it is often a distinct advantage to use a large group of people walking backwards across the fields than a local group of people with a pulley rig. The 1:1 system does not need to be reset, allowing one unbroken pull of the entire rope length, plus the movement imparted to the load is far smoother. The difficulty arises from communication between the pitch and the hauling party as they move off from the shaft – it can often take a few seconds for the 'stop pulling' message to ripple down the team, so you must allow for that in your instructions.

The notion of a 'mass party' pulling team only works if there is either room for the team to walk backwards for the full rope distance or room to loop (where each team member reaches the limit of movement, lets go and runs back to the front). Using hand-over-hand pulling where the team members stay stationary is far less efficient (with only one hand on the rope for most of the time the force exerted is smaller) and imparts far more jerks to the load.
All hauling systems need a safety component, as discussed in section 7b. The 1:1 system is no exception, and some device must be included to prevent the rope from running back should the hauling team lose grip, get tired or suchlike. Basically, the rope must run through something that only allows passage in one direction, such as a rope clamp, descender, etc. Where this is used depends subtly on what the device is, and the layout of the pitch. If you are using a rope clamp (ascender, rescuecender-derivative or similar) then on the intake there is no friction to deal with, but the rope must run straight through the device. It makes sense to place this between the pitch head and the hauling party, as this deals with the danger of the rope being damaged somewhere within the group of haulers. A descender (Stop, etc) on the other hand has high friction on the intake, and so it is far easier to use on a slack rope. If it is placed between the pitch and hauling party, a lot of their effort will be wasted dragging the rope through the descender. If you place it *after* the hauling party then it requires another rescuer to feed the rope through the device, but he will be working with slack rope. The issue of rope damage within the hauling area is slightly worse, but at least you aren't wasting half your strength. One thing to remember if the distance between your pitch and your safety device is long is that when the hauling party transfer the load to the device, rope stretch can lower the load by quite a bit. Also, it helps to dedicate one man to managing the rope as it passes through the hauling party (if you are not just walking the full length) as it can rapidly build up into an unholy mess at the end of the working space.

Of course, as you will be waiting for me to say, you need to be able to access your device at all times as you never know when you may have to lower the load by a few inches. Having to climb out above a shaft to open the gate of an ascender is not best practice!

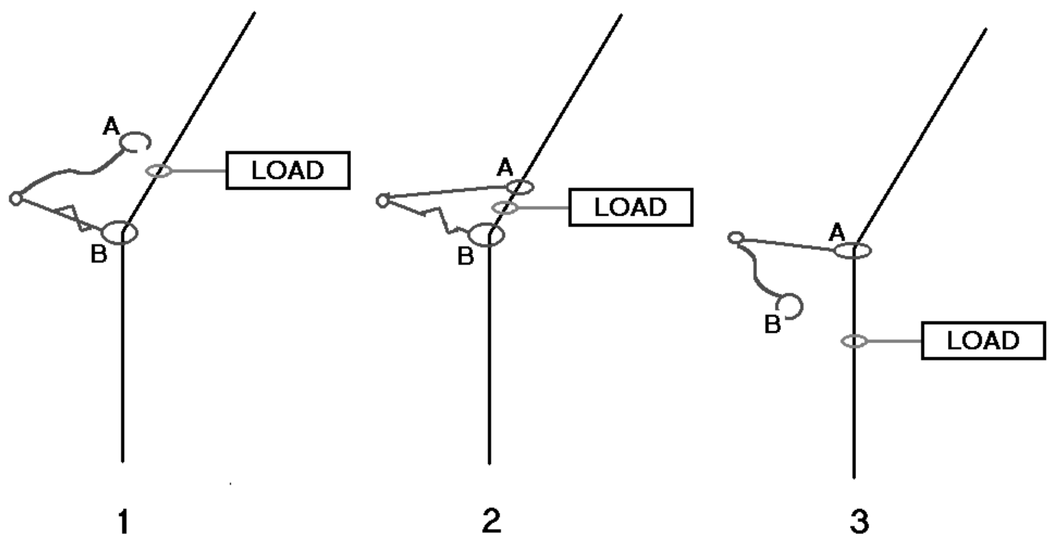
7e. Rebelays and deviations

In SRT caving the rebelay and deviation are common, in hauling they are a positive nightmare and every effort must be made to avoid them. Deviations are not too terrible in comparison, but for both rigs you will lose time and effort passing them, plus need rescuers local to the load and the rig to engineer the system past the problem.

Rebelays are points where a line is fixed to an anchor in such a way that the anchor supports the full load on the line below that point. Clearly in hauling a rebelay is impossible, as the line will be moving. However, when we address advanced rigs in Section 10a we will introduce the idea of the hauled object following a course controlled by other lines (usually at an angle). In this situation, it is possible for these guide lines to be rebelayed. It is also possible to encounter a rebelay if you are performing SRT self-rescue, which is addressed on the next page.

Deviations are anchors that change the route of a line without being attached to it in a fixed position – usually the line simply runs through a karabiner or pulley. They can be applied to hauling lines and indeed often are, however passing them with a rescue load is slightly different from the method used by an SRT caver. The difficulty is that with a higher load it is often impossible to unclip the deviation and then retain the load in position while the deviation is re-clipped. Quite unexpected things can happen if you treat a hauling system like an SRT caver!

Passing a deviation is the same no matter which direction your load is travelling, so let us take the example of lowering past a deviation. Here, the load is being lowered and must at some point be pulled sideways (maybe to avoid the walls of a shaft). Now, it is a very bad idea to try and deviate the load by running a long tail rope below the load, through a deviation anchor and then trying to pull the load across from the foot of the pitch. Apart from the problems of judging distance, it is almost impossible to pull a full rescue load sideways by more than a few feet using this method, and by applying even more tension to the upper hauling lines you are stressing your lowering rig. The usual approach is therefore to fix one or two tensioned guidelines through the deviation, fixed off at the top and bottom of the pitch and to which the load is secured by short slings and karabiners. The load then swings sideways as it is lowered, without needing effort from below or extra tension on the main lines. The problem is that when these slings hit the deviation you must unclip them and move them below the anchor before the lower can continue. Here is where the problem can arise, as a rescuer mid-pitch trying to juggle the weight of a stretcher and unclip krabs is not in a position to exert much force! The most elegant solution to this requires a bit of forethought and a few more bits of rope. The idea is to change the deviation, not the rigging on the stretcher.

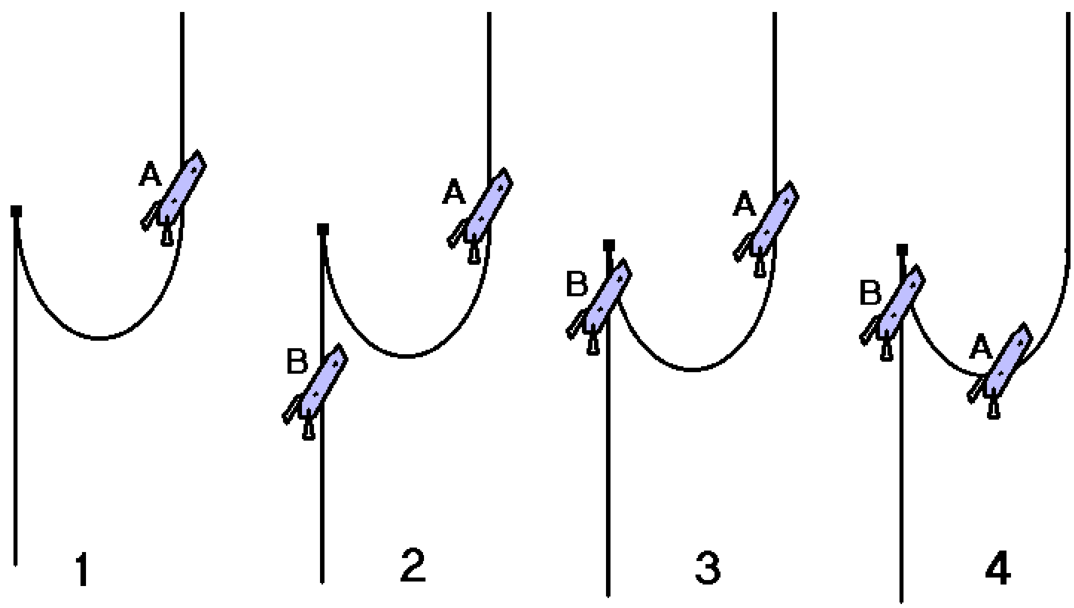


A normal SRT deviation is a fixed sling or rope with a karabiner on the end, through which your tensioned guideline passes. For our rescue deviation, we have two instead of one (as shown in step 1 above). If the deviation is large (and so the weight will be large on the guideline) then one (marked B) should be a releasable belay, as introduced in Section 5i. The other is fixed, but slightly LONGER than the releaseable one and is marked A above. The shorter sling takes the load until the deviation needs to be passed, at which point the stretcher handler clips the second longer deviation onto the guideline *above the stretcher slings* and slowly releases the shorter deviation (step 2 above). The force transfers onto this sling, and the first can be unclipped (step 3) – resulting in the stretcher passing below the deviation without ever being removed from the guideline. The same applies in reverse if ascending the pitch, with the longer deviation being attached below the stretcher slings instead of above them.

Passing a rebelay for assisted or SRT self-rescue

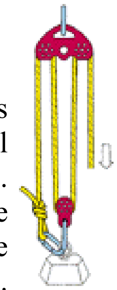
If you are forced to recover a casualty from a single SRT rope by attaching them directly to your SRT equipment and climbing or descending without help, then passing a deviation or rebelay in ascent is identical to normal SRT practice, however it is unlikely that you would have the strength to perform the body-jammer swap with another 100kg hanging from your harness. The solution is to ascend to the knot, attach the casualty to the anchor using one of their cowstails and then reverse-prusik to remove their weight from your harness. You can then unclip them, pass the knot in the normal manner and then re-attach to them using your cowstails. By continuing to climb you can relieve the tension on the anchor and unclip them from it. It must be stressed that assisted SRT ascent is unbelievably hard work and if at all possible the casualty should be taken down rather than up!

To pass a deviation on descent (e.g. on a guidewire) you can usually treat it as a normal SRT operation, taking note of the increased tension when releasing the line. To pass a rebelay needs a little trick to avoid having to lift the combined weight from the anchor, as shown in the pics below. Here the initial rescuer is on descender A. He descends to level with the anchor and clips in for safety, then attaches the casualty's descender B (or any other spare one you can get hold of) onto the rope below the knot – step 2. He pushes it up as far as possible, and clips this into his harness – step 3. Removing his safety from the anchor and descending into the loop of the rebelay – step 4, and eventually the weight is transferred onto descender B, allowing him to release descender A and continue down without ever having to support the weight of the casualty.

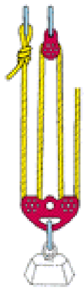


The next chapter deals with the rigging needed to introduce mechanical advantage. Lifting a rescue load (or even a 100kg body mass) without some sort of pulley ratio is beyond many otherwise-fit rescuers, and the simple 1:1 techniques described above should only be applied to lifting equipment less than bodyweight (such as tackle bags or an empty stretcher).

8. Compound hauling



The term 'compound' means that there is a mechanical advantage greater than one, as discussed in section 7a. There are multitudes of ways of obtaining this advantage but all boil down to either a geared mechanical device or a combination of pulleys and ropes. For cave rescue the option of a geared device (a winch or capstan) is only valid for the surface pitch. If your team is commonly called to sites with large entrance pitches (mine shafts, etc.) then arranging a wire or rope winch is worthwhile. Winches are touched upon in chapter 10 but here we assume that you are underground and without access to anything with gears in it. What is needed therefore is a compound pulley block that will allow reduced force on the haul at the expense of increased rope length. The problem in 99% of cases is that there are physical and practical limits on the length of rope used, so you often have to raise the load in stages. This of course demands some method of holding the load whilst the pulley system is reset for the next pull. The solution, again in 99% of cases, is the A-block.



8a. The A-block

The heart of almost all hauling systems is a pulley and rope clamp in combination, designed to allow free pulling of rope in one direction and secure locking in the other. This combination is called an 'A-block', a cannibalisation of the terms 'autobloc' and 'pulley block'. There are an increasing number of purpose-designed products on the market, however creating one from standard components can be somewhat of a black art.

I must introduce one more term at this point, before it leads to much head-scratching as you read on. Any system that allows one-way rope movement has a property called 'runback' – this is the length of rope that pulls back out of the device before the locking action occurs, and is important for two reasons. Firstly it limits the smallest movement possible whilst actually gaining position, and secondly if a shock load is applied to the system whilst hauling in, the runback distance becomes the effective fall distance. Long runback means a higher fall factor and more load on everything else.

A perfect A-block should therefore pass the rope without friction (β close to 1.0) and yet grip the rope instantly and securely on the release (minimal runback). In addition of course it must be able to cope with the loading being placed upon it, be reliable in operation and simple to release. Being able to perform a controlled lowering of the line is an ability of descender-based systems only, though for our intended applications an A-block that cannot be lowered under load is not a significant disadvantage.

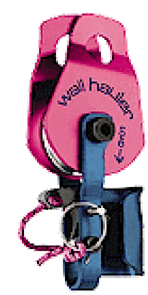
One final important point: A-blocks are intended for hauling and line tensioning only. Their gripping action is 'instant' and ideally they should have minimal runback. As such they are not suitable for use as dynamic belay devices. Belaying a load should always be carried out using a suitable belay device as discussed in section 5g and NOT an A-block. Because of this we will assume in this section that there will never be a significant shock loading onto an A-block. If one should occur then it is likely that the device will fail and the load then be transferred onto the backup lines or minder slings. This is an important point as some of the manufactured devices we will discuss are not capable of surviving a shock load from a 200kg mass but are perfectly suitable for raising one in a well-behaved hauling system. In almost every case the point of failure for a shock load will be the severing of the rope at the clamp (normally a toothed cam) though in other cases where the rope survives then the mounting karabiner or anchor points will undoubtedly fail. This distinction between belay devices and A-blocks is another argument why controlled lowering is not a vital performance requirement, since controlled lowering is far more likely to be requested of a belay system than a hauling system.

The restriction on shock loading at an A-block is critical in that it allows us to use components that would not survive such large peak forces, but which are ideally suited to the task in every other respect. The Petzl Fixe pulley is one such item.

8a1. Choosing an A-block

When planning your team kit there are three options available to you, either purchasing a dedicated device, allocating standard components ready to make up an A-block on scene or using a descender. Clearly once underground you are limited to the gear available on site, and so it is worth spending some time planning what that gear will be before needing to install it.
It is not a simple argument as each option has points for and against…

Purpose-manufactured device:



Advantages

- Ready-to-use without 'building time'
- Reliable and predictable operation and performance

Disadvantages

- Comparatively expensive compared to subcomponents
- Dedicated to one use – parts cannot be 'diverted' to other locations
- More training required in operation

On-site built device:

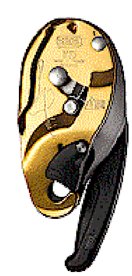
Advantages

- Can be produced from spare equipment to hand on scene
- Can be varied to suit circumstances
- Parts can be re-used elsewhere as required

Disadvantages

- Operation and performance less predictable and reliable
- Training in assembly required

Using a descender



Advantages

- Minimal training required for setup and use
- Reliable and predictable operation and performance
- Can be used for other purposes

Disadvantages

- This application is usually outside manufacturers approvals
- High friction compared to pulley-based systems leads to high anchor loads
- Can easily exceed the rated loadings of some descenders

As with all rescue applications it is rare to find any type of device that is rated by the manufacturer for a full 200kg load. Pulleys in isolation are of course available in suitable strengths but dedicated devices and descenders are often rated only for 100kg operation. The distinct disadvantage of using a descender is that the lack of a true pulley sheave means that the friction within the device is very large. This increases tension in the rope during hauling and can increase the load on the anchor point by several times.

In premature summary I suggest that where resources allow every kit should include a suitable dedicated device, when these are used or not available then constructing an A-block from standard pulleys and jammers is the next best option. Use of a descender should remain the last resort.

8a2. Purpose-designed devices

These are growing in diversity and popularity, driven more often than not by the needs of industrial rope access. Historically there have been 'haulers' produced for climbing where raising of tackle for big wall routes was intended. These devices were lightweight and low strength, as the intended uses were equally minimal. Gradually as the use of hauling systems in industry has increased people have come to realise just how awkward A-blocks can be if not handled correctly, and so manufacturers have leapt at the chance to fill a gap in the market.

There are two categories of A-block currently on offer:

Follower clamps

Here, as in the self-build devices we discuss later, a rope clamp and pulley are mounted together in such a way that the clamp acts on the rope after it leaves the pulley or before it enters. In either case the rope is gripped while it is still straight and before contact with the pulley sheave. Examples include the Kong BlockRoll, Wall Hauler and USHBA Hogwauler.

Wall Hauler

USHBA Hogwauler

Sheave clamps

Here a toothed cam engages on the rope as it passes over the tope of the pulley sheave, and clamps it between this cam and the sheave itself. The rope is therefore gripped at the point it is being bent. Examples include the Petzl Traxion and Pro Traxion.

All designs incorporate a pulley sheave that can be used as a pulley in isolation, by opening or releasing the clamp component. None are intended for use as replacements for personal SRT jammers.

PETZL Pro Traxion

The jury remains out on the exact relative merits of these designs, though for discussion I have some **personal** observations to consider:

Sheave clamps are more compact, though follower clamps can be more intuitive to operate due to the 'open' design and similarity to conventional SRT jammers.

The Petzl Pro Traxion has a 'becket' hole that is used to secure the swing sides into position and must be fitted with a spare karabiner. This obviously allows simple connection to a rope for compound pulley systems that is not always possible on follower clamps.

The major point of contention is the cam position. Whilst not arguing against the performance and design of either device there is a clear difference in the operation under load. Follower clamps grip the rope between a toothed cam and a fixed metal plate, as is the manner of generic jammers. Under loading therefore there is both the positive grip of the teeth in the rope sheath and the friction of the rope against this fixed plate. In addition the rope is straight at the point of contact, so there is no preferential tension in any part of the sheath or core. In contrast shave clamps grip the rope between a toothed cam and the moving pulley sheave, so the only holding effect is from the teeth - there is no additional friction effect. Also, the rope is gripped at a point where it is wrapped over the sheave, so the outer radius of the rope is under increased tension compared to the inner. This outer radius is also the part gripped by the cam, therefore there is a question of how this 'gripping the part most under stress' can influence the failure process. Devices such as the Pro Traxion are tested and fully approved and this discussion is not intended to criticise their performance or suggest faults, however there is obviously an argument that any device working to the optimal design should not apply stress to a point on the rope that is already under increased stress in the first place. In conclusion a follower clamp is probably more rope-friendly and may cause less damage or failures when subjected to high shock loading or extreme static loads. This is reflected in the fact that the working load limit of the Pro Traxion is 2.5kN whereas that of a site-built follower clamp A-block using a Fixe pulley and Basic ascender is 4kN.

Sheave cam devices are however a lot more compact than any other design, and have advantages in applications where size is critical (such as jiggers, as discussed in Section 8f).

This book does not seek to show commercial bias so I will stop short of giving recommendations on which types to buy. What is important is that the device is rated for rescue work and not personal (e.g. the Petzl Pro Traxion is a rescue-rated version of the Traxion) and that the design is intuitive to operate, reliable and suitable for your working practices.

Even if your team includes these devices in kits, riggers must still be able to construct A-blocks from component parts. There is always a need underground for one more system than the kit bags contain, and reliance on specific devices is not an option if there are none left. Aside from this, being able to build an A-block and understand the reasons behind the choice of components and mechanisms of failure helps to predict how a purpose-made device will perform when pushed beyond the rated limits.

8a3. Building an A-block on scene

There are many ways to correctly assemble an A-block and twice as many ways to get it wrong. Of all rigging systems it is probably the one that is rigged wrong most often, and in some cases the consequences can be dire.

The main failing of an assembled device is that the component parts are linked together with flexibility (usually by karabiners). The device is then able to deform under changes in tension, increasing runback. The most serious problem is that if the karabiners are free to move they can on occasion rotate to a position where the load is applied across the gate – a situation leading to failure for the forces involved in rescue. Assembly of an A-block is therefore a battle to ensure that this cannot happen, but even with the best design and careful assembly it remains a problem that must be watched for at all times.

Not all pulleys, jammers and karabiners are suitable for building A-blocks, and even those that are need to be used in the correct combinations. What follows is mainly based on Petzl equipment, as this is by far the most common in use by UK cave rescue teams. If your team uses equipment from other manufacturers you must think carefully about the combinations possible. The pages that follow will show you what needs to be considered.
It is surprisingly difficult to find manufacturer data on how to turn pulleys and rope clamps into A-blocks. Petzl show diagrams in their manuals that relate only to their 'Fixe' P05 pulley. The method of rigging for this device is different to any other, so it is not possible to copy the instructions for other purposes. Before embarking on the methods for swingcheek pulleys I will first discuss the use of the Fixe (which we all know by now would not be suitable for a full-load rescue hauling system).

The Fixe has, as the name suggests, fixed cheeks with a gap between them. The attachment hole will only accept one karabiner, and that must be oval. To create an A-block it is therefore an issue of getting two karabiners where only one will fit. Petzl's solution is to cross-load the karabiners.

The first karabiner <u>must</u> be oval or this simply does not work. For strength the second karabiner (which connects the pulley to the anchor) should be a D-pattern as shown. Following the photograph you can see that the krab through the pulley holes links to the ascender (in this case a Petzl Basic). The correct attachment point for any Petzl-type ascender in a hauling system is through the two top holes, NOT through the bottom hole.

This arrangement works well, with only a small runback. There are however two problems, one of which is serious.

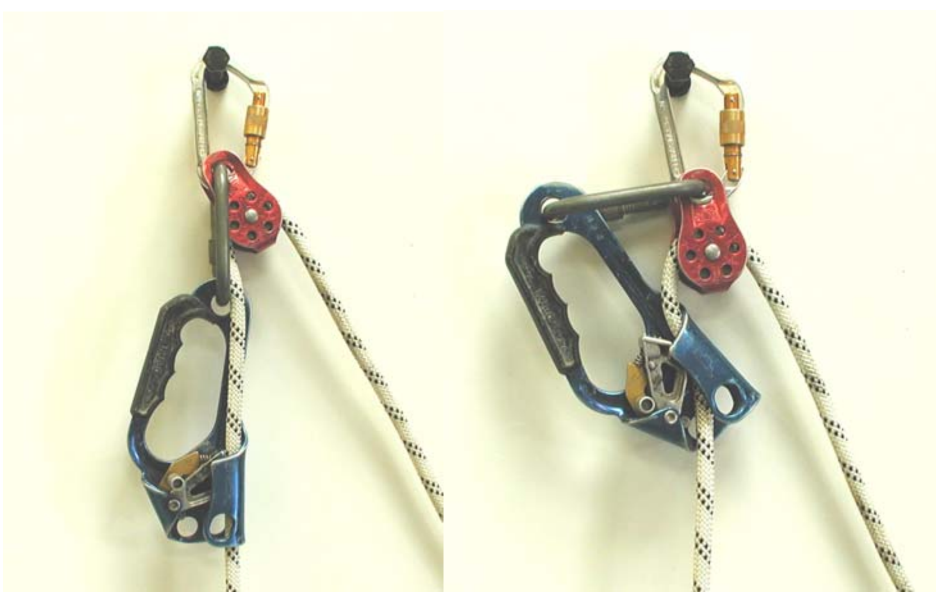
First (and least dangerous) if the jammer is fully opened to pay out, as may happen during initial setup, it can hang against the tail rope as shown in the photo. As the rope is pulled through it can catch the teeth of the ascender and snap it closed. Annoying, but not too dangerous.

My solution to this problem relies on the spare hole in the base of the Basic ascender (which Petzl have yet to find a use for, or reason behind…) By fixing a 30mm length of aluminium bar into this hole (using an M5 bolt) you can provide a riding surface to keep the rope away from the teeth. It does not interfere with the operation, strength or connection points of the Basic and is well worth doing. In the photograph the aluminium rod is tipped with a nylon ball, simply to cover any sharp corners.

The second issue with this cross-karabiner rig is potentially serious, and is the result of the oval karabiner rotating under a snatch load on the main line. As you can see from the photos on the previous page, this oval krab is in compression and therefore unstable. It is possible, either by sudden loading or when the tail rope is moved upwards (anticlockwise in the photographs), that the oval krab will suddenly rotate by 90 degrees, loading across the gate. Obviously this results in an incredibly weak system that is likely to fail under a shock load. The problem with the Fixe is that this is difficult to prevent, by the nature of the design of the crossed karabiners there is little warning of a twist and little that can be done to stop it, other than careful tending.

Runback…

I have seen people (often who should know better) rigging an A-block using what is called a ‘follower clamp pattern’ – where the rope clamp grips the rope on the load side and acts in tension rather than the tail-side compression version above. This is often argued as a solution to the krab-twist problem but can be fatal for whoever is being hauled. Follower clamp pattern A-blocks that are constructed with movement (as you will get when you use krabs to clip things together) can suffer from huge runback and can even take themselves apart. Looking at the pictures below on load and take-in, you can see the problem…



Under take-in the clamp can ride upwards (as the krab acts as a nice hinge). It will either stop at the pulley, or in the worst case it can rotate so that the rope is being pulled outwards through the gate. This can damage the rope, risk pulling it clear or even cause the cam finger lever to become hitched into the pulley. The result of that would be that when the load is returned and the clamp pulls downwards the cam could be opened all by itself!

The solution, which we will use in the next section, is simple enough. The clamp is moving upwards as there is nothing pulling it down, so you can simply pull the clamp downwards by using a small weight or bungee cord. If the rig is vertical then a short sling and tackle bag of rocks will do the trick, for horizontal hauls you will need to use bungee cord, attached to something downline of the A-block.

One final point, a minor one but worth a mention. The bottom hole of the Basic is only rated for 17kN rather than 20kN for the ‘twin’ top holes. Clipping through these twin holes also fixes the rope into the clamp, preventing it coming free even if the cam is opened. The Ascension has a full-strength bottom hole but there is still the issue of a positive capture using the top holes, so if you use an Ascension to rig a follower-clamp, it is worth throwing a spare karabiner through the top holes to act as a safety and the point to tie your weight or bungee cord to.

A-blocks and swingcheek pulleys

As by now you will be bored of hearing, any full rescue loading required full rescue pulleys. Here we use Petzl P50s and Basic or Ascension rope clamps, as they are almost standard for UK cave rescue teams. Most other pulley manufacturers are poorly-represented in UK suppliers, so teams often never bother looking past the P50 for anything better.

Petzl keep very quiet about how to rig a P50 into an A-block, as there isn’t a single straightforward solution. SMC never mention A-blocks and Kong simply advise users to buy a dedicated hauler device. Useful if you’re down a cave and all you have left is a P50, one jammer and a bag of krabs!

Let us start with the most common (and probably the best) variation – the follower clamp. Although we ruled it out for the specific application to the P05 Fixe, it was beaten by a very specific rig for which the Fixe was designed. To make an A-block with a swingcheek pulley demands care and a few extra bits of kit. The runback problem on the previous page, and the solution with bungee cord or a small weight, is vital for all swingcheek-based A-blocks.

Here we have the same follower pattern as we abused in the Fixe section, and it will not surprise you to learn that it does the same things if left in this basic state. Even worse for this photograph we are using the weaker bottom hole of a Basic clamp, so switching to an Ascension clamp would give us a full-strength bottom hole if one were spare. The Basic’s bottom hole is still strong enough if there are no other options, but there’s no point in skimping for the sake if it.

As you can see, without the bungee cord pulling the Basic downwards it will ride up on the take-in and can capsize the oval linking karabiner. Putting some kind of restraint on this movement is absolutely vital for this pattern of A-block. The same applies if you use a becketed pulley and attach the clamp to the becket (which we've done in the photo to prove the point!)

This horrible result not only has about 15cm of runback, it is forcing the gate of the krab against the pulley wheel, a nice metal-on-metal grinding process that does all manner of damage to both parties… as good an excuse for tying it down with bungee as you will ever need.

<u>Back to the compression pattern</u> – copying the Fixe solution but clipping both krabs into the large eyehole of the P50. You can probably imagine the problem with this one – it has very low runback (3cm) but that oval krab is very free to twist – even more so than in the tighter holes of the Fixe.

And so it does. In the photograph you can see that the larger hole size of the P50 has allowed the oval krab to rotate to the point where the top of the Basic is pressing against the pulley, the oval krab is in fact loose. Whilst 'safe' since the Basic will not fit through the cheeks of the P50, it is hardly elegant.

The solution I use is simply to attach a third krab between the base of the Basic and the main line. This forces the clamp to stay 'upright' and whilst the oval krab is still loose in this picture, there is very little runback. You could also use the bungee cord / weight idea from before, but this is a solution designed for those situations where you've lost your bungee and nothing heavy is available!

This third krab method does not work as well for the Fixe pulley, as there is insufficient room within the pulley hole for the oval krab to move. As a result the krab remains under compression when the tail rope is not being pulled, and the probability that it will rotate remains. Having said that it would not do any harm, and anything that is not bad in ropework is by definition worth it if you have the bits to spare.

So what have we learnt? Well, the most reliable A-block for swingcheek pulleys is a follower clamp with some bungee-cord-based tension on the jammer, or a compression pattern with a third tie-in krab. Either will work equally well and is equally safe, so the decision is down to the availability of something to tie the bungee cord to. Learn both patterns and make the decision on site.

The Fixe pulley, on the other hand, works reliably in compression mode as it was specifically designed for it. There are similar methods of rigging in follower pattern but this is defeating the design. All that matters is attention to detail, use of a third tie-in krab and the possible addition of a metal peg to hold the rope clear of the open teeth.

In terms of strength there is no difference in using the apparently weaker Fixe, as the critical failure point is the rope clamp and this is far weaker than the pulleys themselves. The only issue with including Fixe pulleys in kitbags is that they must not be used for rope deviation – that is a high-load application only suited to swingcheek designs.

Help! My pulley has a tiny hole!

Many swingcheek pulleys have holes only capable of taking one karabiner (such as the good old SMC pulley to the right in the photo, as compared to the huge hole in the Petzl P50 next to it). How do you rig an A-block with one of them? Well firstly, going by our rules in section 6a you shouldn't really have this type of pulley in your kitbags as it limits the uses. Sidestepping that issue and assuming you are there and that is what you've got, there is a solution – albeit a rather dodgy one…

If you clip another karabiner into the main pulley karabiner, alongside the swingcheeks, it will push the pulley to one side and create problems of unequal stress and rope friction on the cheeks. What you need to do is support a jammer in the follower clamp position without being able to attach it to the main karabiner. The solution is to clip a second karabiner between the pulley and the anchor, then clip a chain of 3 more karabiners (or a short sling which would be better) from this to the jammer. The inclusion of a bungee-cord tensioning system is vital this time, as without it the chain of equipment will wrap itself in knots when the rope is taken in. If you are using a sling to separate the jammer and anchor krab then a medium length (1 metre loop or thereabouts) is best as it makes sure the jammer and pulley are well clear. Provided the jammer is tensioned back using bungee cord there is no real limit to the length of the sling, but obviously if the A-block is elongated it limits the amount of movement possible in hauling systems as you cannot go past the jammer!

The next section combines the A-block into the most popular compound hauling system, the Z-rig. A-blocks are also used in chapter 9 to construct counterbalance hauls. Of course if you are raising a light enough load then an A-block in isolation (with no mechanical advantage) may well suffice. Even raising tackle bags and equipment it is good practice to use an A-block rather than just lift hand-over-hand, as if something happens to the hauler (encounter with a falling rock or untimely natural death…) the object being raised does not plummet back to the waiting cavers below.

8a4. Using descenders to create an A-block

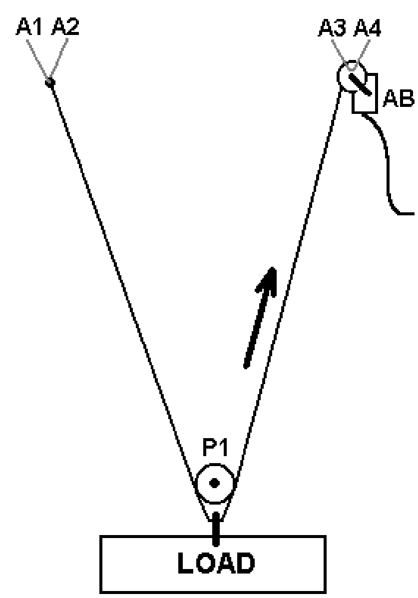
The last option is to use some kind of descender as an A-block. On first thought, any autolocking descender seems ideal to use as an A-block, as it takes in rope in one direction, locks on the other and 99% of the time it does a nice 180-degree bend for you as well.

As with everything in the world, there is a fly in this otherwise-pleasant coffee, and it is friction. Almost every descender is designed around a cam system, with the rope passing around a semi-fixed metal sheave. Whilst it is this contact that provides your controlled descent, it imparts the exact same friction when trying to pull the rope backwards under load. Some devices such as the Stop and I'D impart so much friction that they remove the mechanical advantage of a compound hauling rig built around them! Apart from making it hard work for the rescuers, **there is a more important and subtle problem** – since you are rigging your a-block as effectively a 180-degree pulley, the sum of the forces in each side of the rope are applied to the anchor point and karabiner. Whilst a descender such as the I'D may be rated safely for lowering a 200kg mass (where the anchor krab load will be just that – 200kg), if you have to pull 500kg on the tail rope to draw the 200kg mass up in a hauling system, your anchor is now seeing 700kg! This is the sole reason why Petzl expressly forbid the use of some descenders (Stop, I'D etc) in compound hauling systems.

To this end, I will stick to self-assembled devices in the rest of this chapter and only include one descender – the Grigri. Whilst it does indeed suffer from the friction problem, and using it in a compound system is outside the approval envelope, several years of use by teams across the world have shown it works reliably and the advantages in being able to lower under control can outweigh the loss in mechanical advantage. It is however a team call – if you don't like the idea of using a Grigri then stick to pulleys and jammers!

8b. The V-rig

Beyond a simple 1:1 straight haul, the V-rig is the next simplest system to employ and gives the rescuers an almost 2:1 ratio. All that limits the V-rig is the need for a rope that is at least twice the length of the pitch. Now, before launching into this and at the risk of confusing you, I must make a point concerning the terms 'V-rig' and 'Z-rig'. The difference is that for a V-rig your hauling lines have some sort of pulley that reaches the casualty/load and stays there. With a Z-rig, the pulley does not. I say this to stop any smart types picking holes in my description of a V-rig in the next section!



8b1. Setting up a V-rig

Setting up a V-rig is simplicity itself. First, one end of the hauling line is tied off at the top of the pitch (to two separate anchors A1 and A2 if we are playing by the rescue rules) and an A-block (AB) set up alongside it to receive the other end of the line. Between these two, a pulley (P1) and karabiner is attached to the line, and the pulley lowered down the pitch on the resulting 'doubled' rope. Once at the bottom, the pulley is attached to the load, the A-block is engaged and the system is ready for hauling. There are a few points to note:

1. It is the weight of the pulley and karabiner that help the rope loop to reach the bottom of the pitch – so it can help to clip something heavy to the line if the rope is stiff and doesn't want to play. A few more krabs, a tackle bag of stones or something will help a lot.
2. If you are sending a V-rig line down to a casualty who has a single line in place (e.g. to haul a tired SRT caver mid-pitch) then you can clip the pulley karabiner around his single line to make sure the V-rig reaches him.
3. It is very important with V-rigs that the two halves of the hauling line do not twist together, as they need to move past each other. On long pitches it is therefore important to keep some horizontal distance between the fixed tie-off and the A-block so that the line does indeed form an open 'V' and cannot twist.

A rescuer can be lowered to a casualty on a V-rig, can be sent an empty V-rig after arriving, can take an empty V-rig down with him or the pulley can be lowered to a helpful casualty without a rescuer moving from the pitch head. One temptation that **must be resisted** is the idea of clipping a jammer to the casualty's line, attaching the V-rig pulley to it and letting it slide all the way down. Rescuers can argue that this will let the V-rig reach the casualty without them having to grab it, clip it on and close the krab. My argument against this is on two points:

1. A casualty that cannot perform such a simple task reliably and without help should not be left alone on the rope. Get a rescuer down to them.
2. If for some reason you need to retrieve the Z-rig partway down (such as if the ropes get tangled) then neither you nor the casualty can reach the jammer to open it. You'll have to send someone down, so you should have predicted that and sent someone down in the first place.

The only caveat to my hatred of the 'travelling jammer V-rig' is if you are alone at the pitch-head and have to recover an unconscious caver from an SRT rope or safety line. In that situation the normal priority of rules changes, so sending down a jammer is the only option. Remember though – if your casualty is conscious they can deal with clipping on a karabiner!

Using a pulley at the bottom of a V-rig and a pulley-based A-block at the top, then a force ratio of almost 2:1 is possible. This will allow one fit rescuer (or two normal ones) to raise the unsupported weight of one casualty (without stretcher or other additional weight). It is a very quick technique to recover someone on a normal caving trip who is just too tired to prusik up the final pitch, and in this situation the casualty should remain attached to the SRT rope by at least their chest jammer whilst being pulled upwards by the V-rig. Their SRT rope then acts as a safety backup, and if they get their will to live back they can assist by prusiking at the same time.
A V-rig without a rescuer 'local' to the casualty must never be used where the casualty has a medical condition requiring monitoring, or where the casualty is out of sight of the rescuers at

any point during the raise. The final limit on the use of the V-rig is of course the length of rope required. For hauls of greater than 50m then you may be limited by available rope to using a single hauling line and a local advantage system at the pitch head, such as a Z-rig.

8b2. The V-rig in gorge rescue

Cave rescue teams can often be faced with a situation, underground or on the surface, where a 'gorge' rescue is required. This is defined as a rescue from the bottom of some shaft, opening or rift of an appreciable width where the rescuers must work from both sides to keep the casualty from being scraped up one wall. The classic surface scenario is rescue from a deep river valley where unstable rock or trees make access along the side walls impossible. Underground the situation usually arises in mine chambers.

In gorge rescue, the V-rig is used more as a tyrolean traverse that can be lowered to the casualty (See chapter 10). With one end fixed to the top of one bank of the 'gorge', the rope is thrown across the gorge and a hauling system (A-block, Z-rig or something similar) used to attach the rope to the other bank. The V-rig casualty pulley is allowed to run out into the middle of the rope and the rope lowered until it reaches the casualty. The problem with this scenario is that you can raise the casualty to a mid-air point between the two banks, but you need to ferry them sideways to one bank for recovery. To do this, a separate line must be connected from the casualty pulley to one bank before the V-rig is lowered. Once pulled up to the safe tyrolean limit (120°, as we will discuss in chapter 10) then the casualty can be pulled across to the bank using this separate line. It does not matter which bank receives the casualty in technical terms, so the decision is one of space, manpower, access and anchors. Depending on the situation and relative heights of the banks (they are always the wrong way round) then you may have to physically 'tow' the rescuer out to the casualty and/or tow them back to safety, thus requiring a positioning line to each bank. One thing that is often overlooked when rigging a V-rig gorge system is that the weight of the rescuer and casualty are significant. When they are suspended in the centre of the raised 'tyrolean' and you are trying to tow them up a 30° angle to safety, it requires considerable effort and either a good bank of strong people or a local advantage system such as a Z-rig. Mid-rescue is not the point to find out that you haven't got the strength to get them out of thin air, so plan for something heavy. That way your only surprises will be pleasant ones.

At the risk of stating the obvious, if you are using a V-rig for gorge rescue then the safety lines for the casualty must also be rigged to both banks and the two lines taken in carefully. A safety line going to only one bank will lead to a painful recreation of 'bottle of bubbly launching an ocean liner' should the V-rig fail.

A point worth some consideration, but with limits, is the view of the casualty. Often gorge rescue (above ground) is for a casualty who has no experience of being in mid-air suspended on ropes. They are likely to be more frightened by being literally in the middle of nowhere on a V-rig than being raised against one wall, so where the casualty is obviously frightened and there are NO safety or technical reasons for avoiding the side walls, then using a mid-air V-rig for the sake of it is not the best practice. Teams do not carry Diazepam to permit scary procedures to be used 'cos the rescuers think they look like fun!

The V-rig gives, at best, a 2:1 ratio of hauling. To get more than this needs a bit more complexity, and the next stage up in the ladder of pulley ratio is the Z-rig, which we will see in the next section. Naturally, the Z-rig can be used in conjunction with the V-rig if you need the extra pulling-power, and if your casualty is in a stretcher or is accompanied by a rescuer on the same lines, you will. Always keep in the back of your mind the thought that stacking pulley systems onto each other to gain Biblical amounts of force is only effective to the point when your rope breaks! As the pulley ratio increases above 3:1 you must watch for tension on ropes and anchors, as it is entirely possible to overload equipment without realising it.

8c. The Z-rig

The Z-rig is the basis of almost all UK cave rescue hauling when the load is too great for a simple 1:1 pull. The use of a pair of pulleys and a travelling clamp result in a 3:1 mechanical advantage and a flexible system that is quick to reset.

8c1. The basic layout

A typical 'bare bones' Z-rig is shown to the right. An A-block is secured to a suitable set of anchors and a travelling clamp and pulley (a B-block) is placed on the main line. Pulling on the emerging tail line moves the rope through both pulleys and moves the B-block and A-block closer together. The basic operating principle is 100% simple – pull until the two blocks are close, then push the travelling clamp back along the main line (whilst paying out some tail rope) and start all over again.

In the photograph I have used the P50/Basic A-block design with third krab as discussed in section 8a. The travelling B-block is another P50 pulley and Ascension connected by an oval krab, simply to show that handled ascenders can be used. With either type the oval krab must connect through the top twin holes rather than the bottom hole, as the tail rope can be pulled at any angle and it is important not to impart any leverage onto the B-block.

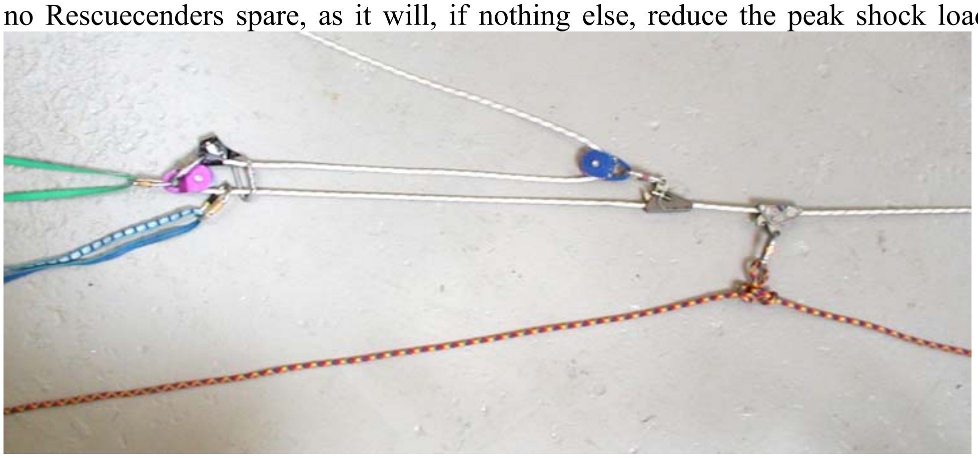
This bare-bones Z-rig is ideal for deadweight hauling of equipment, or as a line tensioner for tyroleans. When lifting live loads (casualties) it is important to protect against failure of the A-block. Even with multiple anchors it is obvious that if the A-block pulley should fail then the load will drop by at least twice the length of the Z-rig. As the tail ropes are not usually belayed, it would be unlikely that the hauling party could arrest a fall even when the Z-rig slack has gone.

There are various solutions for A-block protection. Some teams attach a minder sling (See chapter 6) to the main line just as it enters the A-block pulley, this running to separate anchors. If the A-block fails the load moves to this new anchor point with very little runback. Assuming the A-block clamp survives intact and thus cannot pass through this now-loaded krab, the rope will not free-run and with increased friction the Z-rig would probably remain in working order, at least until emergency repairs can be done.

A second option is to put a downstream clamp on the main line, to deal with any possible failure of the Z-rig including rope break at the A-block. This should be as far away from the Z-rig as possible to allow for slipping, and is often fitted at the point where the main lines divert over the pitch-head pulleys. The problem with this approach is that in the event of an increase in loading on the main line (such as from connection of the stretcher) the rope between the downstream clamp and the Z-rig now cannot stretch. The single downstream clamp takes the entire load, with the Z-rig drawing tension back onto the main anchors only after the haul has begun. The same applies to any shock loading on the main lines (for example from deviation

failure). Clearly this downstream clamp was intended as a safety backup, not a main anchor. It is not simply a case of adding slack into the downstream clamp by using a webbing sling or similar, as now there will be a larger runback if the Z-rig fails. The only option is to choose a clamp that is as rope-friendly as possible, and make sure it is more than capable of supporting the full rescue load on it's own. In the photo to the right we achieve this using a Rescuecender. Note that it is fixed to the anchors using dynamic rope – we expect it to receive a small shock-load if our main system fails, so a direct connection with slings is not possible.

A Petzl Shunt can be used though as we have discussed earlier, it must be expected to slide a long way. A positive-action compression clamp such as a Rescuecender is ideal as slipping is minimised yet the griping action is still 'friendly'. Toothed clamps (Basic, Ascension etc.) are suitable but less rope-friendly in the event of a full-load shock incident. Personally, my suggestion is to stick with the A-block minder sling and assume that rope failure within the Z-rig is not as likely as A-block anchor or connector failure. Adding a downstream Rescuecender for very high load hauls is worthwhile but only as a method of reducing the peak shock loading on the A-block anchors in the event of a problem on the pitch. A Shunt on its own will not be able to support a full 200kg load with a shock start but would be worth putting on if there are no Rescuecenders spare, as it will, if nothing else, reduce the peak shock load on the Z-rig.



The photo above shows a full belt-and-braces Z-rig with a minder sling and downstream clamp.

8c2. The Grigri Z-rig

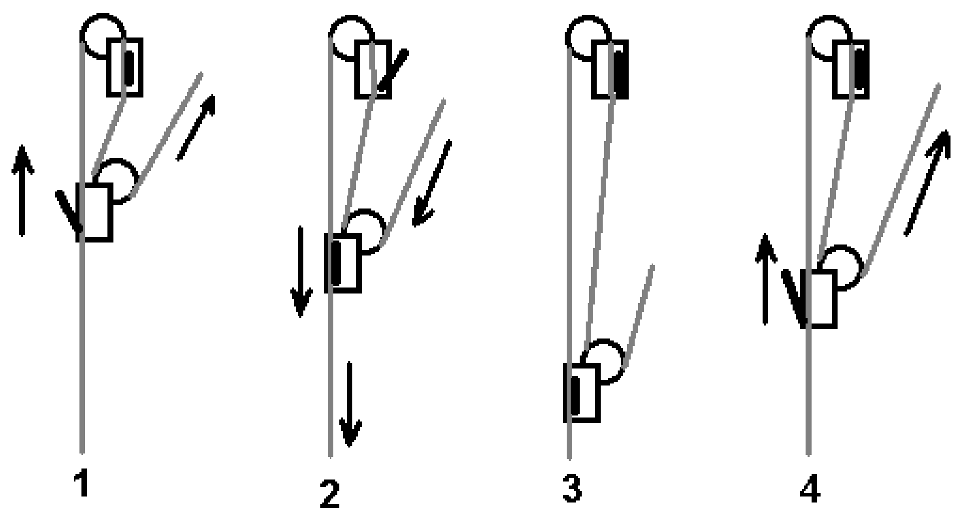
As discussed, a Petzl Grigri offers an alternative to a pulley/clamp A-block but at the cost of far more friction, since there is no rotating bearing. The same rules for the rest of the system apply, and the Grigri is rigged as normal. It offers the ability to lower through the Z-rig with ease, but at the cost of reduced mechanical advantage. The main difficulty in using this system in UK cave rescue is that the Grigri is specifically intended for use on dynamic ropes only, and as a belay device for climbing. Use with static ropes and as part of a hauling system is plainly beyond the purpose specification and also the limits of the CE approvals. Whilst practical tests show it can work, legally it could be an issue of negligence through intentional misuse of equipment. The decision is therefore one of liability not suitability and I will not suggest a course of action in either direction.

Many teams use the Grigri in Z-rigs without thinking of the friction losses, suitability for use or strength simply because they have seen others do it, and thought it must be a cool thing to do. It's a classical example of a piece of kit being adopted widely on an initial assumption rather than being thought about on merit. If you see another team using a rig you are unfamiliar with, think (and ask) why they are doing it, if it is any better and **then** decide if you want to copy them!

8d. Lowering through a Z-rig

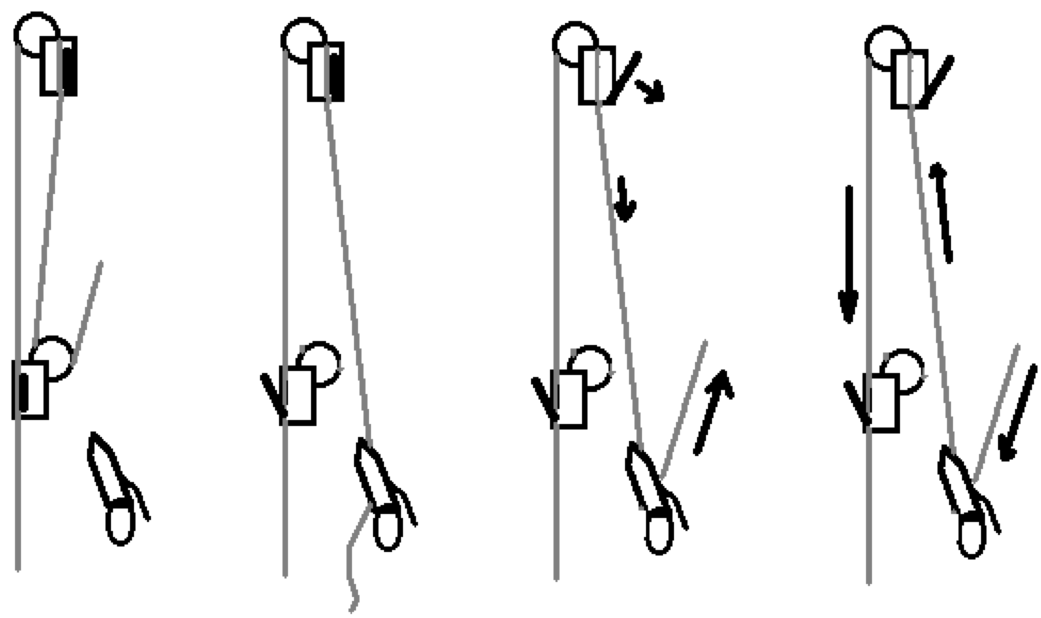
By the very nature of a Z-rig, lowering is not easy. Apart from the Grigri-adapted Z-rig, where lowering is simply a case of paying out through the Grigri whilst controlling the load on the tail rope, lowering on a conventional Z-rig is a slow and uneven affair:

1. The travelling B-block is moved as close to the A-block as possible (but not into contact!) and the hauling party prepare to take the load on the tail rope.
2. As the load is taken, a rescuer releases the A-block clamp cam – using the finger method and most certainly not by opening the cam completely.
3. With this cam released, the tail rope is paid out until the travelling B-block has reached the limit of motion. The A-block cam is replaced.
4. The B-block is released and returned back to the A-block, the process is repeated as required.



For a long lower this is not practical and the technique can also impart a large bounce to the lines, creating problems of casualty care and extra loads on the anchors. It is suitable for small adjustments, for example if a load has been raised a few feet too high to enable access to a rebelay or level in a shaft. For a lower of more than five cycles of the Z-rig it is easier and faster to convert the rig to one of the two lowering modes.

Mode 1: partial conversion



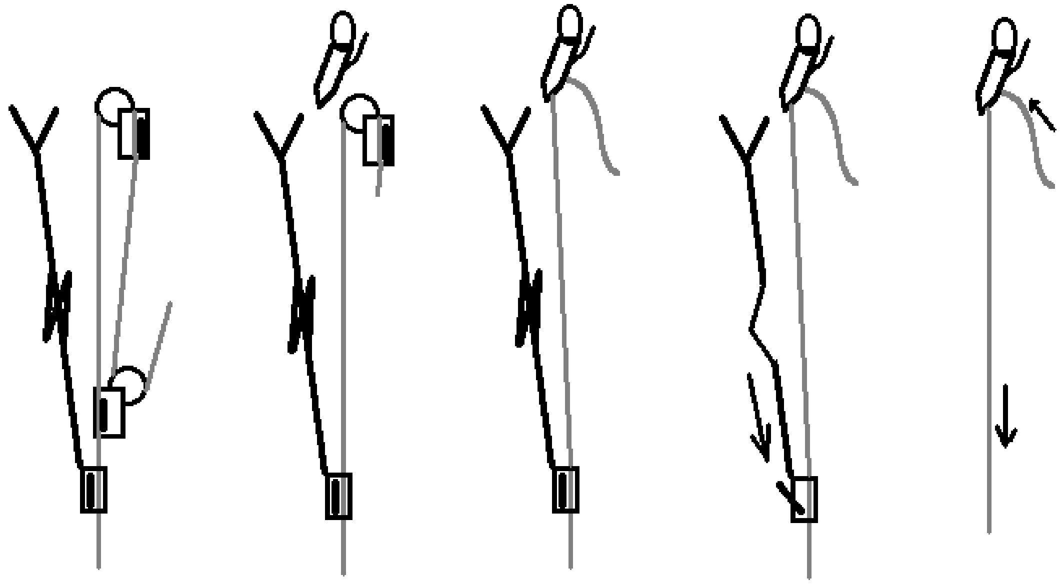
This is the fastest option and allows equally rapid return to the Z-rig, but requires an anchor point somewhere in the vicinity of the end travel of the B-block, and those anchors must be able to take load *towards* the A-block.

The idea is simple. With the A-block taking the load, the travelling B-block is moved up to these anchors where a descender is fixed to a sling or short rope, so that it can operate in 'free air'. The tail rope is fed into the descender (removing it from the B-block pulley), leaving the B-block effectively unloaded and redundant on the main line. The cam on this clamp should be opened so that the B-block can slide freely. By pulling in on the tail rope again (this time through the descender) the load on the A-block can be released to the point where this clamp can also be opened. When the tail is paid out the load will be supported on the descender, via the pulley of the A-block. As the descender pays out the main line slides past the unloaded B-block. If at any point the Z-rig is required again, simply close the A-block cam, release the tension in the descender and put the tail back into the B-block.

The disadvantage of this mode is that to initially release the A-block cam, the rope must be pulled through the descender – a point of high friction. It would be possible to use a jigger (see section 8f) if these were available, applied upstream of the A-block to release tension on the entire system while the cams were opened and the descender fitted. If you used a Grigri for your A-block this isn't a problem, as you can release under load without taking in any rope so wouldn't need to go through this conversion process. However, as we've said a Grigri-based rig is high friction all the time.

Mode 2: full conversion

Where a long lower is needed and time is not critical, or where there are no suitable anchors for the partial conversion route, the entire Z-rig can be removed and converted to a lowering rig. This requires (as well as a descender device) a medium length sling, rope clamp and karabiner:



1. The sling and new clamp are connected to the same anchor(s) as the A-block, or two nearby, and the clamp applied to the main line downstream of the others.
2. Pushing this out to the point of tension, the Z-rig is paid out fractionally, transferring the load to this new clamp and sling. The entire Z-rig is then unloaded, so the B-block can be removed.
3. The A-block is removed and the descender fixed to these anchors and to the rope.
4. Using a spare rope (or the tail of the main line), a line is rigged from one A-block anchor, through the original B-block and out as a tail.
5. The B-block cam is closed and this spare rope used to pull in the line slightly, to allow the third clamp to be released and removed.
6. The spare rope is let out, leaving the load on the descender. The B-block is opened and lowering commences.

If the third clamp is attached using a releasable sling (see section 5i) then there is no need for the B-block to be used to release the tension. This has the advantage of being able to lower without needing to take in any distance on the main line whatsoever – useful if the main line is jammed or the load was too heavy to lift. The drawings above show this option.

Someone asked me why go into all this talk of converting Z-rigs when you could just hold the load on the second line, strip things down and put in a lowering device such as an I'D. The answer (or should that be the excuse?) is that if you have a casualty mid-pitch with two lines to him, and you remove one completely to rebuild a lowering system, you are leaving them on a single rope. We said that was a silly idea, and so the last two pages had to be written!

8e. Modifications and improvisations

Cave rescue rigging does not often get more complex than a Z-rig, which hopefully by now you will realise means it doesn't get complicated at all! However, the best-laid plans always die on the route to the callout, so you can expect to be faced with having to rig your Z-rig without all the kit, in an amazingly awkward place and without enough anchors. Remember that apart from two pulleys, an SRT-equipped caver carries everything needed to make and convert a Z-rig (two clamps, three karabiners and some short slings). If you have to result to cannibalism, remember that the chest jammer (Croll) should only ever be used as the B-block device – it is not suited for incorporation into an A-block as the holes are twisted.

You can improvise a B-block using a prusik knot if need be, so the absolute bare minimum for a functional system with some nett mechanical advantage would be a prusik loop, three karabiners and one jammer (you could risk a prusik loop for the A-block as well, but controlling it on the uptake is much more fiddly). If you only have ONE pulley, adding it at the B-block makes a huge difference, adding one at the A-block makes less as the rope movement over this point is only half that at the B-block per pull.

There are some 'tips' worth noting about Z-rigs that I suppose I should mention:

1. The system is not only less efficient if the tail rope is pulled in a direction that is not parallel to the main lines, but it can make the line bend at the B-block and possible cause rub points on downstream passage walls. It also introduces more bounce.
2. The golden rule of hauling must be followed – make gradual smooth pulls to minimise bounce. This leads to increased system loads and motion sickness in the casualty.
3. The A-block is a pulley with a 180-degree turn, so the anchor load is twice that in the main line. Always use a minimum of two discrete anchors for the A-block, as well as separate anchors for any minder slings. The main krab in the A-block must also be a big, beefy steel affair capable of taking the high loads.
4. A long Z-rig slide means fewer cycles and less bounce, plus greater ability to lower without resorting to conversion. With very long Z-rigs (on the surface for example) watch that the three lines between A- and B-blocks don't wrap around each other.
5. Always make sure that someone can physically reach every clamp (including any downstream safeties) at all times. They will all need to be released at some point…
6. It is rare to rig a Z-rig in the vertical plane in the UK, but if it was to be rigged vertically then a small object (a chain of krabs or small bag of rocks) can be used as a pull-weight to make the B-block return under gravity after each cycle. If you do this, remember to satisfy rule 5!
7. Practice, and keep a jigger handy.

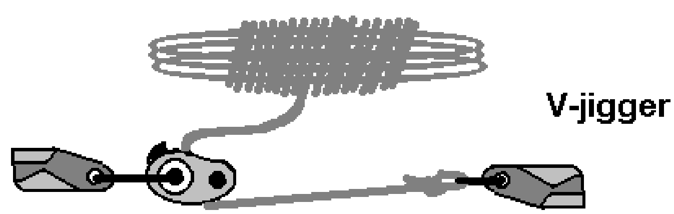
8f. Jiggers

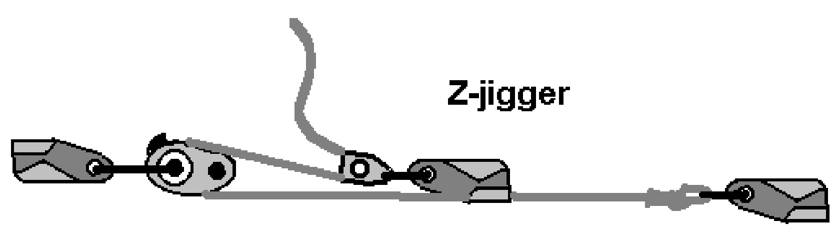
'Jigger' is an American term, as can be realised from the fact it means 'a device to jig'. Jigging, of course, means 'to pull like a madman because something isn't working right'. I will use the US term as the British phrases for such emergency measures are far more anatomically-related, as is the way for the tongue of the Brit under stress….

A jigger is basically the bare bones of a Z-rig plus some clamps to piggyback it onto a rope, pre-built and packed in a bag ready for use. It is designed to allow tension in a line to be released locally, for example when converting a full-sized Z-rig to lower mode or to release a karabiner from an anchor when the line is still in tension. Jiggers must be able to take a full rescue load but are not expected to experience shock loads, as they are only temporary additions to the ropework. As such many teams in the US use smaller-diameter cord (e.g. 9mm static rope). This is chosen for physical size and weight, but as a typical jigger only uses 10m of rope, full 11mm line is pretty acceptable and abides by our earlier rules about never using less than 11mm rope underground. Although designed to stay in one piece it is always possible that at some point the rope from a jigger will be cannibalised for some other emergency use, and having stray bits of 9mm around is not a good idea. Dynamic rope is not suitable as the jigger must collect the tension quickly rather than spend time stretching itself. You can argue over the 9mm/11mm issue but do not say I didn't make the point!

There are several 'types' of jigger:

1) Z-jig: a full Z-rig with the A-block connected to another clamp. Self-locks, so can be used to raise in steps just like a full-size Z-rig.
2) V-jig: One A-block mid-rope with a connecting clamp, and one clamp at the end. Allows a 2:1 pulling ratio and self-locks, but can only be pulled in once.
3) Open jig: As above but just a pulley mid-rope – not self-locking and so can only be used to hold tension off the main line for a short while.

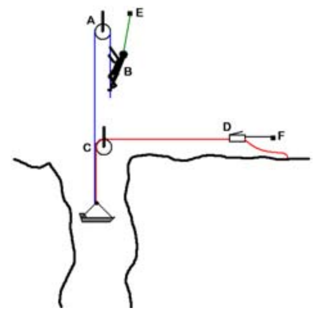




The A-block in a jigger needs to be physically small (so that the available movement per metre of rope is maximised) and so a sheave-clamp device such as the Pro Traxion is a better option than pulley/jammer constructions. It is not suggested to use a Grigri as the payoff in higher friction outweighs the benefits.

Note that since a jigger is permanently rigged, the knots should follow the rules of permanent rigging and be sealed. The tail end of the 10m rope should not be knotted to prevent the jigger being taken apart, as often you find you'll want to!
Jiggers have become very popular in the USA but are rarely used in the UK. Given the relatively little size, weight and cost of putting one into a bag and keeping it handy, I can see no reason why UK teams cannot find a place for them. Apart from the obvious advantages in their use for all manner of quick hauling system repair, they can be handy for other uses (shifting an annoying boulder, pulling a steel beam into position and so on). Added to that is that fact that to have a solution to an emergency is the best way to ensure that the Gods do not send one your way.

9. Counterbalance hauling



In the previous chapters we dealt with raising a load using force applied to the lines (via pulley systems and one-way devices) by members of a hauling party. An alternative method to this approach of having men standing around and pulling on ropes is to use the weight of something or somebody to counterbalance the weight of the load, thus making the effort of the hauling party far less. The basic premise goes back to our notes in Chapter 1 – that the average rescuer cannot apply more than his bodyweight to pulling on a rope. If you use him as a counterbalance you therefore get more out of him! There are of course advantages and disadvantages to this idea:

In its favour the load on the hauling line is reduced and the effort required by those hauling is reduced, possibly allowing less men or a less mechanically advantageous system. It therefore comes into it's own when rescuers are scarce.
Against it are the complexities of rigging (as you will see shortly) and the balancing of weights and distances.

This 'complexity of rigging' will raise eyebrows, as many times I have seen teams and text books treating a counterbalance hauling system as some kind of glorified balancing act over a pulley. **This is not how it works!** Please please take this part to heart, it is vital. You use a counterbalance weight to *assist the hauling party*, not to replace them. You still need the same twin-rope hauling system, anchored and controlled as usual, it's just that you can do away with some of the pulling team.

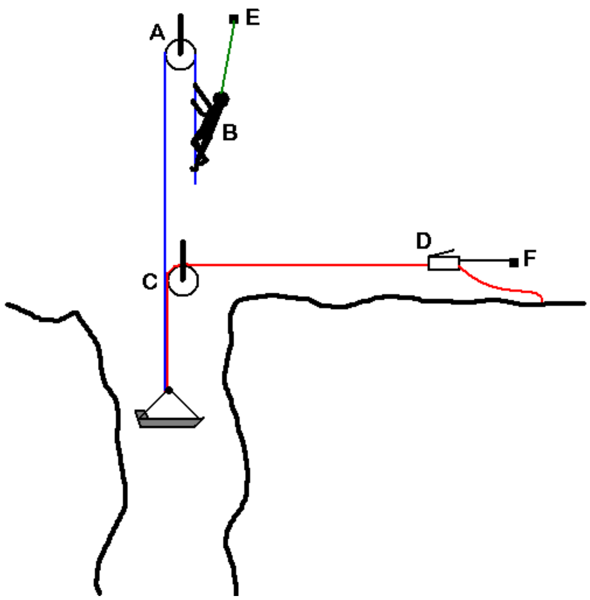
The idea is to reduce the load, not remove it!

The worst thing you can do is put too much weight into your counterbalance and turn an assisted haul into a runaway descent, where your casualty flits past three hurtling rescuers mid-pitch as they each head towards opposite ends of the planet. If in doubt use less weight – after all you were originally intending to haul the load up by other means anyway!

The result of this drum-bashing is that the ropes used in the counterbalance are separate from the hauling system and should never become part of it, even as some kind of safety line. Think while you are rigging – you should be able to remove the counterbalance completely without changing the hauling system at all.

9a. Top haul

The most common counterbalance is where the balance weight starts at the top of the pitch next to the hauling party and is allowed to descend (ish…) as the load rises. In the simplest sense we have the 'travelling balance' system, where a single rope equal to the pitch length runs from the load, up through a top pulley and down to the balance weight (which we shall assume is a rescuer in SRT gear). As the load is raised, he descends, passing the load mid-pitch. This works fine if there is physically enough room for this passing to take place but you need to judge the length of the rope carefully, as the idea is that the balance hits the floor as the load reaches the take-off point. More common is the steady-balance system where the team member climbs the rope and aims to stay still as the rope moves past him:



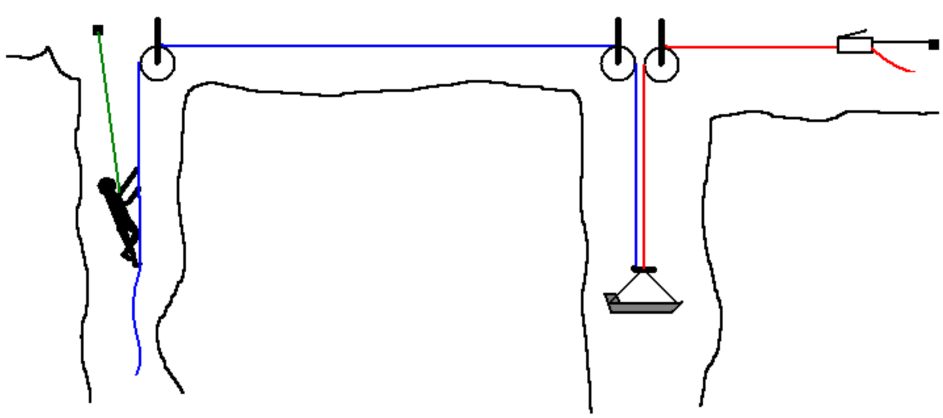
In the pic to the left I've shown this first variant on top-hauling. Here, the load is being raised using the red line and some conventional method of propulsion, probably a hauling party at D. The main pulley at C and jammer/anchor system D/F take the load, but for whatever reason some extra help is needed. Using a higher pulley at A (so it's out of the way), and a second balance line (in blue) we connect a team member B to the stretcher and as he climbs the blue line using SRT, he assists in the haul. A single safety line (green) links him in position; otherwise there would be no way to release him from the stretcher when it comes time to clear the pitch. If there is a need to temporarily lower the stretcher then the balance man needs simply to prusik down a bit.

NOTE: in the above diagram I have omitted the standard second safety line for the stretcher for clarity (as there are enough colours already!). The blue balance line is NOT a substitute for this safety line, since it will do very little to hold a fall, until the balance man is squeezed through the top pulley genitals-first.

As you can see, the issue with a static-balance rig is keeping the poor balance man out of the way! He needs to be either well above or well below the main pulley and pitch-head, so he doesn't interfere when the stretcher is unloaded. If you have the headroom, then placing him higher is better, as the stretcher never needs to pass him and (often) he is in a better position to observe progress and self-regulate his climbing.

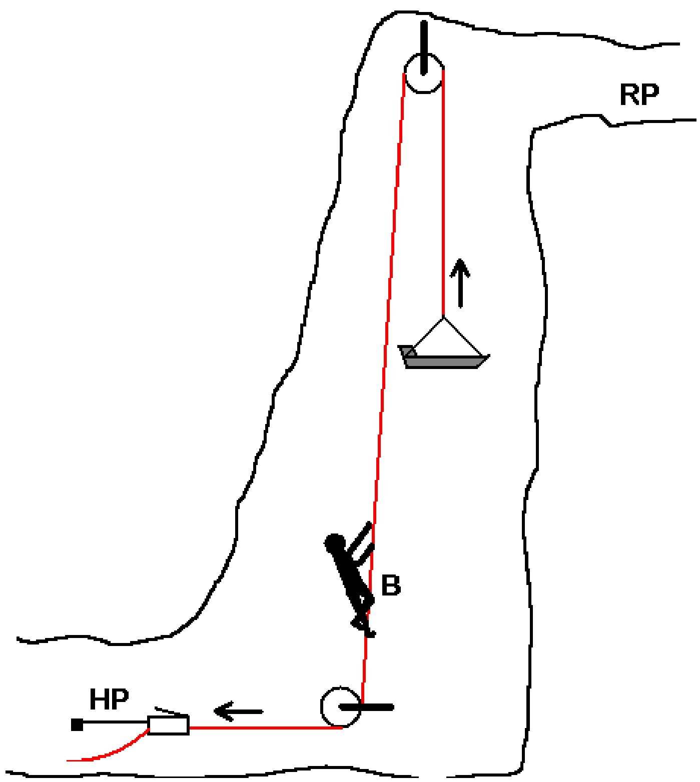
Looking at the above diagram you can also see that the balance man can remove himself from the rig at any time simply by letting his weight transfer onto the green line and disconnecting from the blue one.

A final point on top hauling – there is no rule anywhere that says the balance man has to be descending the same pitch as the load! If you have two pitches nearby (as with many mine shafts where the shaft is split into two halves) you can run the balance man down the 'empty' pitch to keep the hauling route clear:



9b. Bottom haul

Here, the hauling party are at the bottom of a pitch, raising the load to a waiting reception party using lines that pass over pulleys. This may be needed if the pitch head is very constricted and there are no suitable anchors for the hauling system, but should be quite rare in practice. There are two options in this case, the first being to use the same counterbalance ideas as in the previous section, with the balance man positioned wherever he can operate without getting in the way. The other option, and one **specifically permitted in this application only** is to place the balance man on the hauling line as shown below. He ascends the line using SRT as it is pulled down through the rig, therefore remaining a few metres above the ground at all times. It is permissible in the bottom hauling scenario as the balance man is never exposed to a large fall risk should anything happen to the main lines, and his presence will not interfere with the operation of the system at any stage.



To the left I show this idea (again omitting all the second lines). The hauling party HP are trying to deliver the stretcher to the reception party RP, and there's precious little space for any conventional counterbalance. Taking great care not to climb more than a few feet above the ground, our balance man B climbs against one of the main lines, adding his bodyweight to the hauling force.

He must be able to disconnect from the line (either by switching onto another rope or descending to ground) at the point when the load is being delivered to the reception party, as the line will need to be made slack at some point. There must also be a second line without a balance man for safety of the load (i.e. do not use two balance men, one on each line!). The essence of this rig is of course that nobody can pull a horizontal rope with their full bodyweight, but can hang on a vertical one thus imparting more force for a set number of men at HP.

This method does increase the tension on the balanced line and the associated anchors, however it is a useful trick to keep in the back of your mind should you need to apply more force on a bottom haul for some reason, as you can quickly add a balance man to the lines without having to fit another pulley and a counterbalance rope to the system. The technique cannot be used in top hauling systems as it relies on an 'empty' section of line both vertical and moving downwards. Above all, NEVER put two balance men on the same line – that will increase the loading on the top pulley to a point over the acceptable rating.

9c. Inanimate balances

We have created the methods above using an SRT caver as the balance weight. There are no reasons why he cannot be supplemented by inanimate objects (tackle bags of rope, etc) but you should never use such objects as the sole form of balance. The essential aspect of using a caver is that they have the power to move along the balance rope and remove themselves from it if need be, whereas a bag of rocks remains there until it hits the floor. If you need for whatever reason to release the balance line and your weight hasn't reached the floor, you are in trouble! So by all means add to your balance man's bodyweight by covering him in coils of rope and bags of sand, but resist the temptation to make use of that tree trunk lying near the footpath, unless you think you can teach the woodworm to operate a descender!

This is the end of part two of the three-part edition

This part was last modified on 11 May 2003

Changes in this issue: Expanded the counterbalance section and added diagrams.

Life on a line

Part Three

A manual of modern cave rescue ropework techniques

Dr. D. F. Merchant

Published online at draftlight.net/lifeonaline issue 1.1

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The book is published in three parts, as divided below. This is part 3. It should not be read or republished in isolation from the other parts, to which important references are made.

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IMPORTANT NOTE

This is part three of a three-part publication. The material within this part is subject to the disclaimers of liability, intent and suitability as given in part 1. This part is not to be used in isolation.

The book is periodically updated to reflect changes in the current technology, legislation and team practices it uses. If you intend to use this book as part of any commercial or legally-liable training procedure, you must ensure that you are using the most current issue of each section. The authors do not accept liability for omission or error between issues.

10. Advanced rigs

This chapter covers some of the remaining devices and rigging as well as tensioned traverses. By the end of it you will have enough methods to deal with any rigging situation, however choosing and using the correct one is down to your skill and experience as a rigger rather than the pages of a book.

10a. Traverses and Tyroleans

I have placed this section in 'advanced rigs' not for the complexity of construction, but for the complexity of the mathematics. Rigging a traverse is easy, but being able to tell someone the peak loads on the anchors involves a lot of quiet contemplation. It is all too easy to get things horribly wrong without ever realising it.

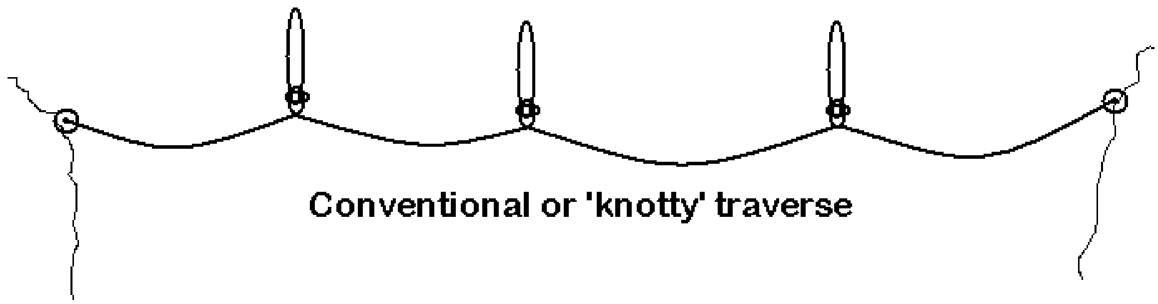
A 'traverse' is my general term for any loaded rope along which the load is caused to move and which is essentially horizontal. I know that sounds very legal, but a lot of things can be traverses when they're not! A guideline at 45 degrees to pull a load away from a hazard is just that – a guideline – and not a traverse. The deciding factor is that a traverse supports the weight of the load whereas a guideline does not.

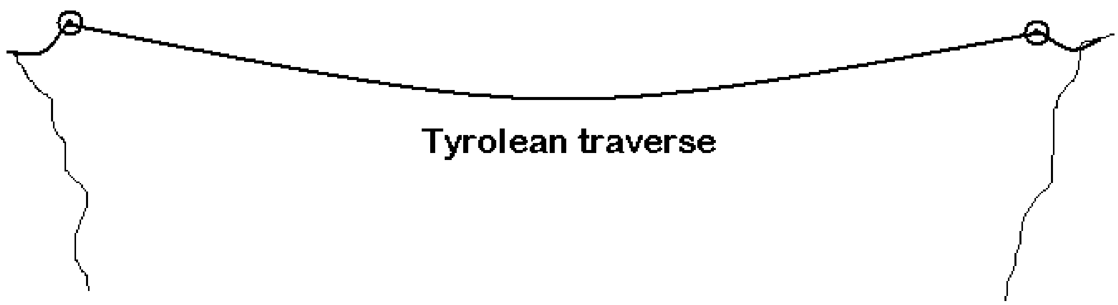
A Tyrolean traverse is a single long span of rope for conveying a load across a hazard, such as from one side of a gorge to another (or from one building to another if you're that way inclined!) and where the load is controlled remotely from the ends.

At this point of course many team riggers are shouting angrily at the screen saying that my definitions are not correct. Well, they are mine, and as far as I can tell there are no references to caving ropework in the current entry for 'traverse' in the Oxford English Dictionary! Seriously, My ideas as given above are just so that I can set these chapters out sensibly. If you think a traverse is not a traverse if it's got a rebelay on it, then fine. But let me know what else to call it!

So, we (I) have two general scenarios. A 'knotty' traverse where the load passes along a roughly horizontal rope that is fixed at several points to the walls and therefore must pass between knots and junctions, or a Tyrolean traverse where the load slides along a single un-knotted span of rope and has only to avoid becoming a ballistic missile. Both, in practice, are nightmares to organise OR nightmares to use. You either build something without thinking and reach brain-failure in the middle of your rescue when everything grinds to a halt, or you plan and calculate like a boffin and watch things work... or at least fail in a predictable way!

The two prime problems with any traverse are the loads on the rope and the control of the moving object. Ropes loaded at large angles experience far higher tensions than the simple weight of the casualty, and it is all too easy to reach a point in a traverse where a section of rope is taking close to it's ultimate breaking strain, even with relatively small weights on the system. Similarly, raising and lowering a load has the advantage of gravity keeping things in line. A horizontal rescue has gravity trying to prevent movement in either direction! A seemingly smooth line of horizontal traverses when rigged can turn into a nightmare set of huge V-shaped valleys and cliffs when you attach cavers to it. Allowing for this and using the right combinations of extra lines to add teasing little pulls in the right places is the key!





For cavers using SRT equipment, the knotty traverse is usually easier to pass than a Tyrolean, partly due to the lack of vertical 'droop' under load and partly as more than one caver can occupy the traverse at one time (subject to them not sharing the same loop of rope). In contradiction however, a rescue load (an inert object or stretcher) will usually find a Tyrolean easier and faster to pass, as all of the motion control and tugging can be done from the ends. Whenever a rescue load has to pass a belay point in the middle of a traverse, you have to get rescuers out there to manhandle the load, disconnect and reconnect slings and so on. If the traverse is truly free-hanging with no rock to get a toe-hold on, then even the simple job of lifting a stretcher by a few centimetres to unload a karabiner can be a Biblical task.

At this point therefore I am going to make two 'sweeping statements'. I don't do this very often, but like buses, they come along in pairs.

Unless the terrain absolutely insists on it, do anything and everything humanly possible to avoid knots and rebelays in a rescue traverse.

And…

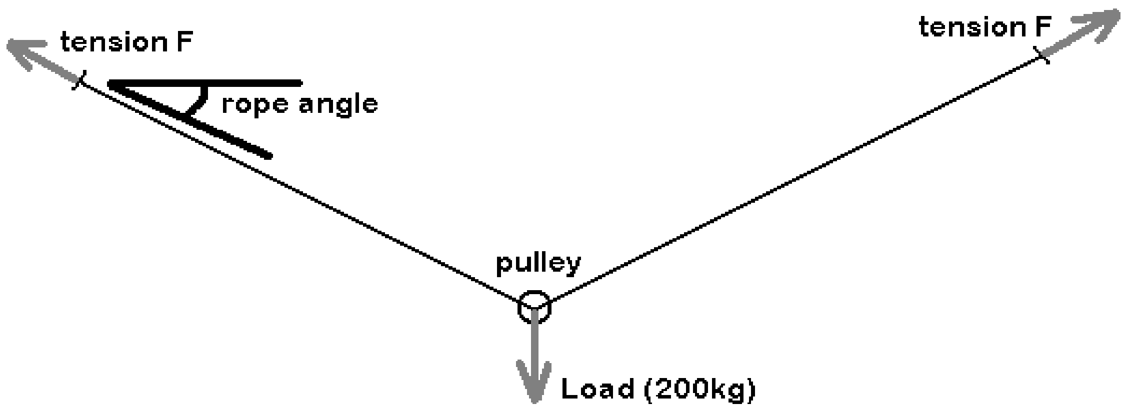
It is easier to make a knot pass your load than your load pass a knot.

(cue confusion)… what I mean (and will explain in the following pages) is that using rebelays that can be removed and replaced as the load passes through them removes completely the need to unhook your stretcher, lift any weights, or perform all manner of aerial acrobatics.

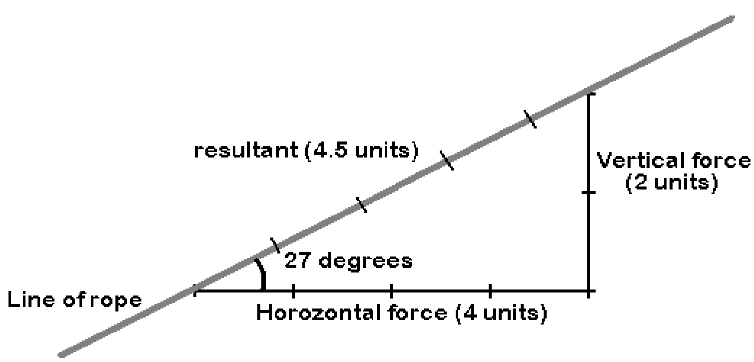
But before we embark on the chaos of using traverses, we need to delve into the mathematics of rigging them. Welcome to vectors 101, there will be a test at the end of the lesson…

10a1. Vectors, loads and traverses

In Section 5d we touched on the loads experienced by pulleys, where peak forces add depending on the angles between them. These rules, the mathematics of vectors, govern the behaviour of traverses too. Whenever you place a load on a section of traverse you are pulling vertically downwards, yet the load on the anchors is off to the side, creating a Y-shaped set of forces as shown below. Remember, since rope bends, apart from the weight of the load the forces acting on the traverse MUST be along the line of the rope.



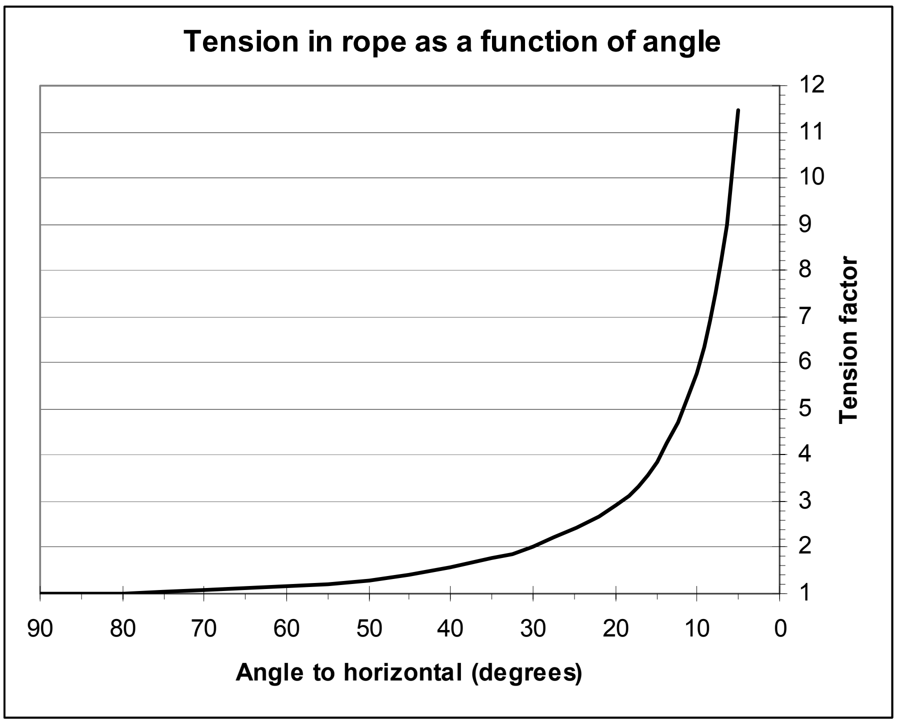
Newton jotted down that unless things are going to start moving about, the forces in every direction on a system must equal out to zero. That means that for the forces acting vertically down (which we'll take as the weight of the load) somewhere in the system there must be one or more forces acting vertically upwards that, in total, exactly equal the weight. But in the diagram the force on each anchor is off to the side! Well, we can think of it as a combination of two forces… one acting vertically and one horizontally, together adding up to make our off-angle force along the rope. We can make these forces by drawing a little triangle alongside the 'real' force (called in mathematics 'the resultant'). In the diagram below we see that our little triangle is 2 units high and 4 units wide, due to the resultant (the rope) being at an angle of about 27 degrees to the horizontal.



What does this tell us? Well – in the first diagram above we said that the sum of the upward forces equals the weight of our load. Since the tension on each end of the rope is equal (more on this in a moment!) and the angles are equal, then we have 2 units of upward force at each end, total of 4 units. Let's say for argument that our load is 200kg – therefore a 'unit' is 50kg. Now look again at our triangle in the second diagram. It says that the vertical load on the anchor is 100kg, but the horizontal load is 200kg! How about the total – the third side of the triangle? Well, with Pythagoras you can see it's given by $F^2 = 2^2 + 4^2$, or the force F = 4.5 units, which is 225 kg. Remember that if we drag each side of the traverse together you will see that what we really have is a 2:1 pulley system, so each end of the rope should only see 50% of the load, or 100kg.

With the traverse stretched out to 30 degrees, the force on each end of the rope has increased by over 2 times!

This is a common enough example of an angle – a traverse with the ropes at about 30 degrees below horizontal – and yet the tension on each end is already more than the weight of the load. Just by looking at the diagrams above you can see that as the angle gets smaller, the load increases even more. But the important thing is it doesn't increase in a nice linear way. To start with, as the angle moves from 90 degrees (rope vertical) towards zero (rope horizontal) the tension in the rope only grows slowly. Indeed, by 30 degrees it's only just over twice the original. The things get bigger quicker. At 15 degrees the load is 3.8 times bigger. At 10 degrees it's 5.8, and at 5 degrees it's 11.5 times the original. In our example above, a 200kg load would place a tension on our rope of over a ton!



Working it out in the field

So you're rigging a traverse and it's hanging there… how do you work out the load without a calculator? Well, it's not that hard to get an accurate guess, if you can't remember the graph above! Start by putting something on the rope so it tensions into a V-shape instead of a curve, which will show you the end angle at the anchor. Then, against the rock or somewhere suitable, scrape a vertical line down from the rope and mark off some units. They can be anything – if you're working it out for a man load, then make a finger width 10kg and mark off 8. If it's a rescue load, then maybe a palm equals 100kg. Anyway, you get a line. Then go horizontally from the bottom of this line until you hit the rope, and mark that point (muddy fingerprints are great pencils!). You now have the same load triangle that we used on the previous page – so you can use your measuring device (finger!) to see the horizontal and resultant (along the rope) forces just by measuring the triangle's sides!

Remember that under load even static rope stretches, as a result the true angles will be larger than you get from clipping a tackle bag to the rope. But as we know now, larger angles mean less extra force, so if you're safe with your muddy-finger triangle then you'll be safe with your full load. The only exception to this is using wire cables, where stretch isn't a factor. With wire, angles must be calculated very carefully as it is possible to achieve very small angles if you don't allow slack, and this can of course lead to *massive* tensions in the anchors!

NOTE: For Tyroleans with a small angle of deflection then several publications give a shortcut formula that is roughly accurate without using Pythagoras... if the 'sag' is the vertical deflection of the rope when loaded and the 'span' is the straight-line distance between the anchor points, then:

$$Tension = \frac{Load * Span}{4 * Sag}$$

This works reasonably until the sag becomes more than 25% of the span.

10a2. Rigging traverses

I am not about to tell you how to rig anchors (we've done that) or how to rig a knotty traverse (that's basic SRT). Few cavers use Tyroleans though, and fewer still have the issues of safety and redundancy to deal with.

Let us say that we have a deep water-filled cavern to pass using a Tyrolean (Harrison Ford moment….) and that the issue of getting a rope from one side to the other has been solved, you have sufficiently huge anchors at each end to take the loads and that you must send over a stretcher and medic. The initial checkpoints are:

1) are the anchors high enough and back from the edges enough to let us load and unload the stretcher easily?
2) Given a safe angle to the traverse of say 20 degrees, will they drown in the middle?
3) Is the end point higher than the start or the other way round?

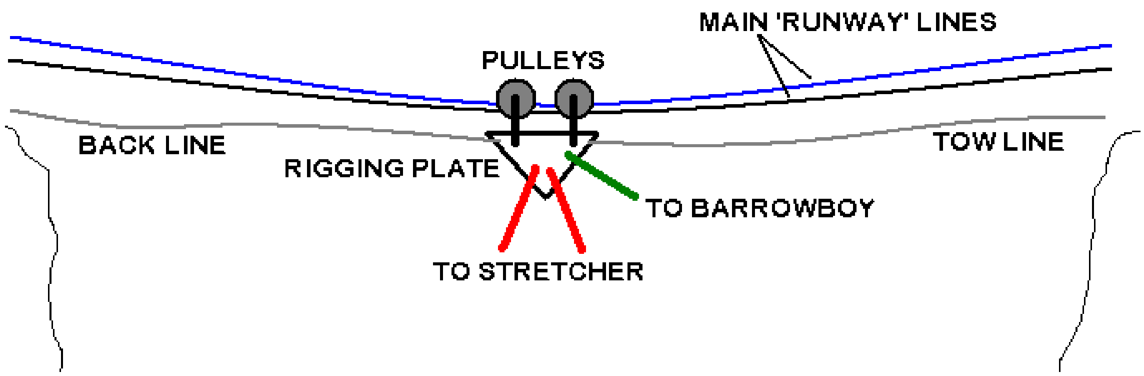
1) is a matter of rigging and by now should be second-nature to your rescue brain. 2) may demand that you put some intermediate rebelay in place, and 3) decides if the team at each end are pulling or letting out. Remember that to pull a stretcher uphill, especially the last few metres, requires a lot more effort than to let out lines from a descender, so share your men accordingly, even consider Z-rigs or suchlike.

Now the components of the traverse itself. You should have guessed these by now even if you've never seen a Tyrolean!

1) A **pair** of tensioned lines acting as the runway for the traverse. Yes, a pair, as we are in rescue mode – so we need a backup don't we! These lines are called 'runway lines' in this book.
2) A tow line (or front line) from the load to the destination so the team can pull it across
3) Another tow line (called a back line) from the load to the origin, so the team can both let out the load in a controlled manner and pull it back if something goes wrong

4) Optional – a single independent runway line as a backup for the medic or barrow-boy, to conform to our safety rules as there are two people on the system.

Our stretcher is to be connected to the runway lines using two pulleys, ideally that span both lines (using a big pulley such as the Petzl Kootenay) otherwise you will hit problems if the runway lines get twisted. The medic will hang on these pulleys too, and optionally be connected to a single pulley on his independent backup line. Please note, and this is important: If your medic is connected to his own backup line he must NOT be connected to the stretcher directly. Should the stretcher connections fail then his backup line may not support the combined load of him AND the stretcher. The medic should also carry in his SRT kit a spare pulley or two, so that in dire cases he can travel along the traverse independent of the casualty.



The origin party, who lower the stretcher out from their end, initially controls the motion along the traverse. Until it reaches close to mid-way between the ends the load will be trying to rush ahead and so must be lowered out. Once it passes the midpoint, the destination party have to haul in. Both ends must remain controlled however, if for no other reason than recovering the pulley blocks back to the start for the next trip!

The actual use of a Tyrolean traverse as shown in the above diagram is relatively simple, but takes effort. There is always a compromise between having very taut runway lines (and hence little sag but high anchor loads) and slacker runway lines, making the sag greater but putting less stress on your gear. The exact level of sag is a matter of experience and judgement, based on the calculations we have discussed a few pages back.

As with all hauling systems, the complex stuff is when you are loading and unloading the stretcher at each end. Careful pre-planning is essential to make sure that the runway lines are high enough to enable the load to arrive safely, and that there is enough distance before the pulleys hit the anchors so that the stretcher can be unloaded a safe distance from the edge. Underground you may not have the luxury of high anchors, and so you will often have to resort to using the tow and back lines to physically haul the stretcher off and on the traverse.

The effort involved in tensioning the lines and hauling the pulleys in the last few metres must not be overlooked – you will almost certainly need a mechanical advantage system of some form to do this safely. However, you must resist the temptation to use a simple Z-rig to tension your runway lines. When locked off, a Z-rig holds the rope using an ascender, and given the fact that our runway lines are known to be taking a very large tension, gripping the rope using a toothed cam is asking for trouble. It is far safer to use a friction system such as the Dog and Tails knot to hold the runway lines, with a Z-rig *behind* the Dog and Tails to haul in the rope, but which is released slightly when the runway lines are set, so that the anchor forces are transferred through this friction knot instead. To release the runway lines the Z-rig can be re-tensioned to loosen the Dog and Tails before removal. Also, similar logic should apply to the far end of the runway lines – it is stronger to secure these using a Dog and Tails system in front of the final knots than just knot them directly.

For a long traverse (not common in the UK but possible elsewhere) then there are several purpose-designed tensioning devices for runway lines, usually relying on a winching action.

A Tyrolean can be the basis of several more complex rigs with only minor changes. It is a very useful base technique to learn, and agreement in advance on the way your team will use traverses saves a great deal of 'discussion' on the pitch! Above all, the following rules should apply:

1. Only one rigger decides on the design details. It must be agreed in advance if communication between the endpoints is difficult.
2. During the transit of the stretcher, the barrow boy calls the shots.

When training, remember not to leave a set of runway lines under tension for prolonged periods, as it stresses the rope. If you are taking a lunchbreak, loosen the lines!

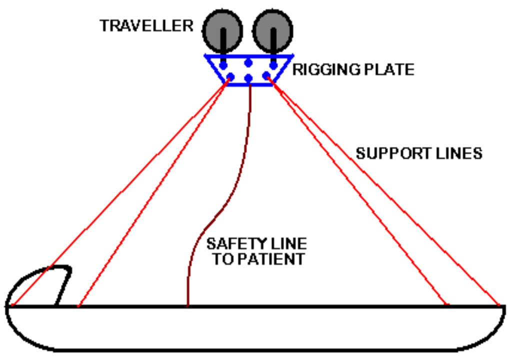
Steel cable traverses

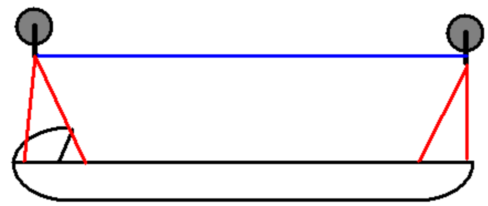
For very long spans or fixed traverses, a lot of industrial teams will use steel cables. They have the advantage of lower physical size and far less stretch (and hence sag) but their use must be implemented with care.
Firstly, the cable must be rated to support the tensions involved. Steel wire cables usually have a breaking strain of 180kgF per mm^2. Secondly, fixing the cable is often a major point of weakness. Steel cables are usually finished in a swaged eyelet, and any anchors rely on this one point of attachment, as it is difficult to secure any further devices to the cable. Tensioning the cable requires either a cable made to exactly the right length or a winch to draw in the excess securely, since ropework systems such as the Z-rig do not apply to steel cable.

In particular, never be tempted to use winching systems not rated for live loads (such as the common Tirfor cable puller). They may be strong, but they are also prone to failure in nastily fatal ways!

ASIDE: Fixing the stretcher

There are two basic methods of securing the stretcher to the traveller pulleys, assuming that you are keeping it horizontal. In all but a few cases you will be, and if you are not then the method is fixing is pretty self-explanatory!





The first option is to hang the stretcher like a bag of groceries (called a centre hang) using long ropes from each end of the stretcher to a single set of pulleys. A safety line to the patient can also be fitted as shown, or they can be linked to the stretcher itself. The second option is to end-hang the stretcher using two spaced pulleys and shorter ropes. A linking rope (in blue) ties the pulleys together so that the towing action on one pulls the other along in unison.

Which you use is not just a matter of preference. For a Tyrolean or a long-span traverse then the centre hang is essential, as an end-hung stretcher will tilt to match the angle of the runway lines. In a Tyrolean, these runway lines are often at an alarmingly steep angle at each end, so the casualty is in danger of being held head-up at one end and head-down at the other!

The disadvantage of the centre hang is that it is impossible to cope with rebelays. Knot-passing pulleys can be used to pass knots in free-air, but passing an anchor is plain old not going to happen, since you cannot release the load on the traveller pulleys one-at-a-time. This is where the end-hung stretcher is the only option… and leads us nicely on to:

10a3. Knotty traverses

As we have said, a 'knotty' traverse is one where there is one or more mid-span rebelays in the runway lines. For a single caver, a knotty traverse is often easier to negotiate, but for a stretcher it is both slower and potentially more dangerous. The major difference is the presence of people – to get a stretcher past any mid-span anchor you will need team members out there to clip and unclip things, lift and pull and push as required. They have to be supported by some means and must be numerous enough to do the job but not get in the way of progress. In a tight knotty traverse (such as the infamous Battleaxe) then the presence of these helpers can make the entire enterprise a logistical nightmare.

The basic premise (and calling it basic does nothing to make it simple) is to use an end-hung stretcher and to pass each end over each rebelay as it moves, exactly mirroring the way a caver crossing a knotty traverse uses his two cowstails to pass knots. At any one time at least one pulley is secure on the traverse, so calamitous failure of the passing-over operation will not cause total loss of the casualty. Doing this in practice is the sort of job you can only manage by lots of practice and lots of liberal application of rude words. Moving a stretcher on a knotty traverse has been likened (and very accurately too!) to watching ants transport leaves: from a distance the leaf flows over obstacles, but up close there are ants hanging on all over the place passing things about like the world is about to end.

If I said here 'neglecting the issue of rigging the traverse….' Then a lot of you would just accept that and read on – however, it's far from obvious how to do this in reality. You're rigging for rescue now – so we need two of everything. Two lines in parallel are an option, but then they'll share the mid-span anchors, and will it make the passovers more or less complex? Do you know? (do you care…)

In reality, for a knotty traverse there are two options and a cheat. (as always!).

1. Rig another knotty or Tyrolean traverse some distance ABOVE the loadbearing one, and use long safety lines to fix the stretcher to this backup system
2. Rig parallel lines on the traverse and let them share mid-span anchors if needed, but have independent end-point anchors.

Option 2 is only realistic when option 1 is not possible, since it increases the confusing mass of ropes for the team to handle. A higher-level backup traverse can be controlled by a single man moving along it and transferring the safety line over, provided that he does not unclip it when either end of the main traverse is removed, the backup rule is relatively unbroken. The anchor points for the high-level traverse may also be useful to support your team members at the passover points, since they cannot use the same anchors as the stretcher.

And the cheat – rig your traverse using steel cables and high-strength anchors, then trust it. This is not an option for impromptu rescue, but has been pre-fitted to common routes, such as the famous rescue traverse in Kingsdale master cave stream passage.

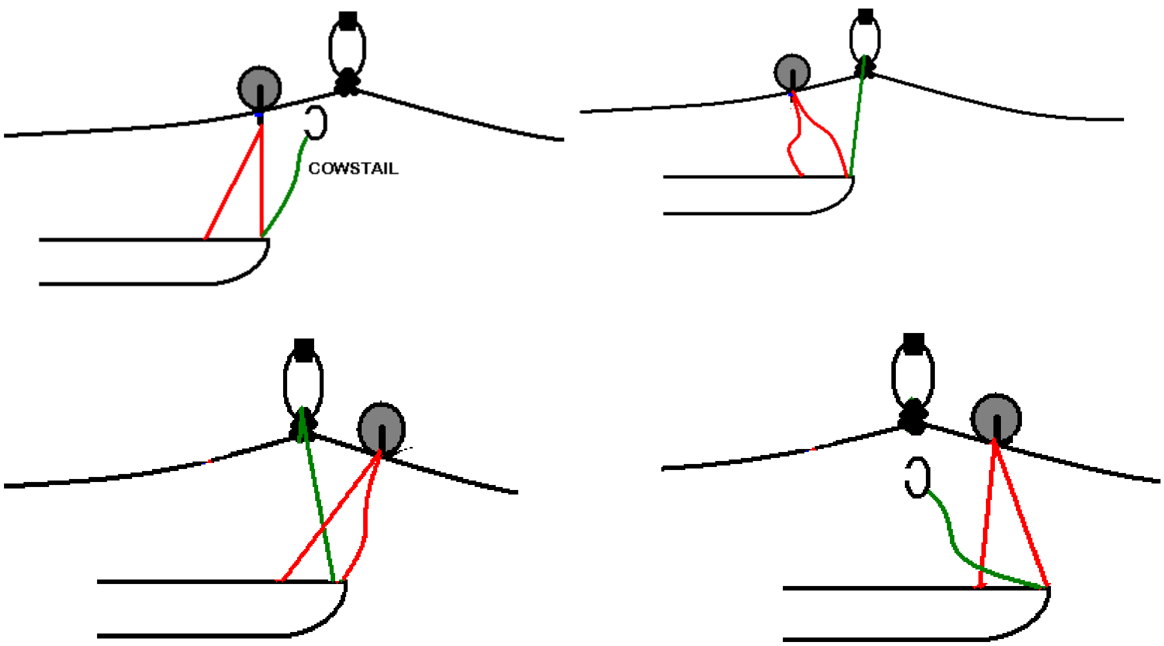
We will assume from here on that we're using a high-level backup of some form, and deal with the logistics of moving on the main traverse only.

One final point that will become clear in a second… when you are tying off your mid-span rebelays, make sure that it is possible to clip a karabiner directly into the anchor, or into the loop of rope from the anchor to the knot. If you use maillons to connect a butterfly knot to a hanger, then you may like to change them to karabiners for this exercise to give a nice open clipping-point.

Unless a span on our traverse is long, I suggest that using tow and back lines is not usually worthwhile. Having a short line coiled on the stretcher to use if need arises is fine, but it's far easier to physically move the stretcher between hands where that is possible. You are going to encounter issues with the stretcher tilting, since it is fixed from both ends, but that is a price to pay. It is possible to engineer adjustable ropes on the stretcher to compensate for the tilt if you really need to (if the medical condition of the casualty requires it), but in normal cases that adds time and complexity to the rigging with little benefit. So, the stretcher moves out onto the rope and is pushed and pulled up to the first rebelay, where we have one or more team members positioned from miraculously-placed anchors (or the high-level traverse).

The end of the stretcher arrives close to the knot, and you must support it while you physically unclip the pulley, move it past the knot and reattach it. To do this, a short length of rope from the end of the stretcher, a few inches SHORTER than the ones going to the pulley, is used. If you have team members about, then it is physically not that hard to lift one end of the stretcher a few inches up while this 'cowstail' is clipped directly into the anchor. Now you see why we needed to make that clipping-in easy when we tied the knots! The pulley will then be just slack enough to let the rigger swap it over, then another quick lift and the cowstail can be removed, leaving the stretcher to move on. The same then happens at the back end using another cowstail.

One little hint – make sure the riggers out in mid-air have a few spare pulleys clipped to their harnesses. With many designs of pulley to remove it from the rope involves removing it from everything, and it is wonderfully easy to drop at that point!



The four diagrams above show the sequence in action – without the people and confusion normally found underground when trying to run this type of traverse! Based on this, you can see that a knotty traverse without footholds is to be avoided at all costs, since lifting the end of the stretcher by hand really needs a team member with a foothold to push against. If you have not got the luxury of footholds, or you can only have one man operating on the traverse, then you need to be able to load and unload the cowstail without needing a free hand to deal with the stretcher too. In that case, a simple adjustable cowstail (using a Grigri or a descender as a releasable hauling device) will work much better. Putting the Grigri at the top of the cowstail allows the team member to use his weight and a 2:1 advantage to lift the stretcher, even if he has no secure foothold to lift from normally. It is of course vital to use a device that can be released under load – a pulley/jammer combination would be impossible!

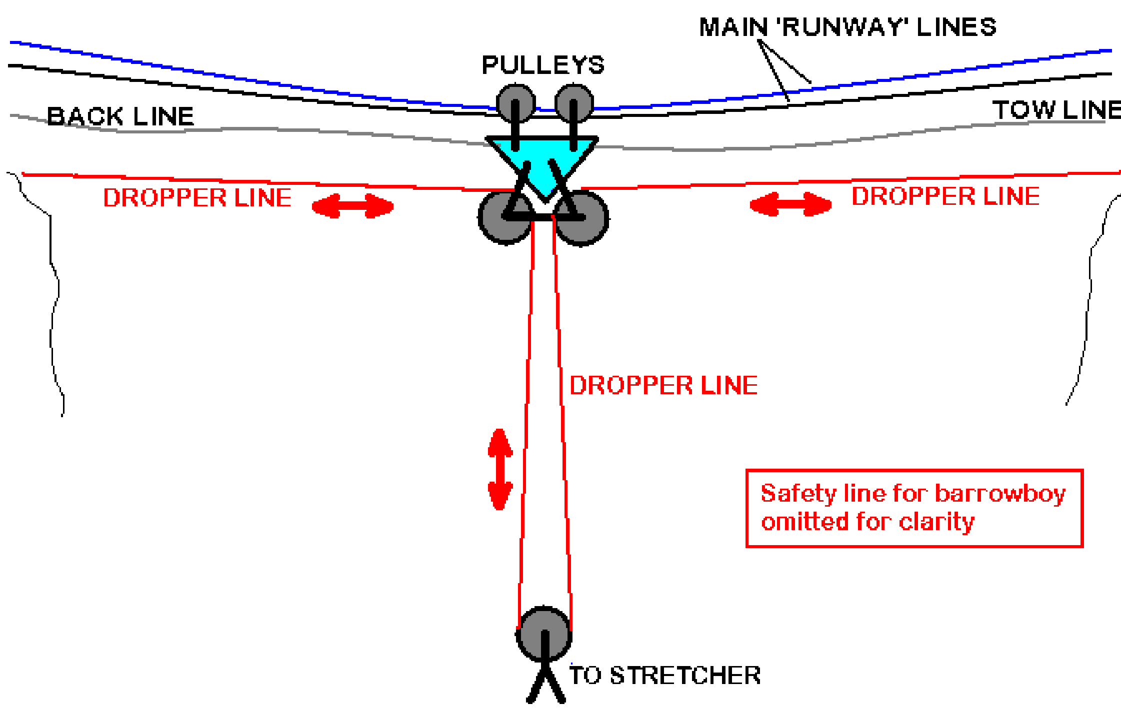
However, sometimes tortuous winding rifts and knotty traverses are not your problem – equally fun to deal with is a deep open gorge with overhanging edges and a casualty at the bottom!

Cue…

10a4. Crane Jib traverses

This technique, used to great effect for these restricted access gorge rescues, is so named after the way it behaves like the jib of a tower crane. A Tyrolean traverse is used to span the gorge, but from the traveller pulley block a vertical system of ropes is used to raise and lower the casualty/rescuer from the middle of the runway. Although complex to rig, the crane jib traverse offers unlimited movement in a rectangular plane under the traverse, allowing it to reach anywhere, even with trees or cliffs blocking the route for a simpler V-rig (Section 8b).

The basis for this system is a full rescue Tyrolean as we have described above, giving us a 'traveller' pulley block moving over a pair of runway lines, and held from each bank by tow and back lines. Then comes the clever bit. A new rope is rigged across the gorge, but routed through two new pulleys clipped into the traveller. The centre of this rope therefore hangs in a vertical loop below the traveller, and a pulley on this makes us our raising/lowering system. Paying out or pulling in this new rope from either bank moves the casualty vertically and independent of the position of the traveller. We will call this new rope the 'dropper' for want of a better name. Yes, I *am* making all of these terms up as I go along, and *no*, nobody else seems to have found a better set and published them!



To use it therefore, in essence, the traveller is sent out to the right place and the tow/back lines tied off securely, locking the traveller in place. The dropper is then paid out, the casualty connected and the dropper pulled in. Once raised, the dropper is secured and the traveller moved again to bring the casualty to the bank.

But what happens when the traveller moves? Surely the casualty goes up and down? Well no. That is why the dropper runs from BOTH BANKS. The vertical position of the load is set by the total length of the dropper between each anchor, not the position of the pulleys and bends, so as the traveller is moved the dropper slips past the pulleys and to a reasonable extent the casualty stays put!

For a real system, practice has shown that a single SRT line, fixed to the traveller and used by the medic ‘conventionally’ is better than letting him/her ride on the dropper on the way out. It’s an issue of confidence, but the medic is often happier being self-propelled. You can satisfy your redundancy issues by either using another dropper in parallel (which gets very complex if you don’t practice this system a lot!) or running an ascender on a free-hanging backup line from the traveller. Since the traveller is connected to the banks by 4 ropes, it can be taken as ‘safe’!

Also, in a real system there will be some vertical movement of the load as the traveller slides, due to the stretch in the runway lines and the dropper. However, as your load is on a nice 2:1 pulley system, it is quite simple to adjust the vertical position as you go. On occasion I have used an exercise to practice this, by spanning a lake and making the team send a stretcher across the surface without getting it wet, but without letting it rise more than a foot above the water. Not exactly walking on hot coals, but just as fun if you dare to put someone in the stretcher while they practice!

<u>Aside: failures on traverses</u>

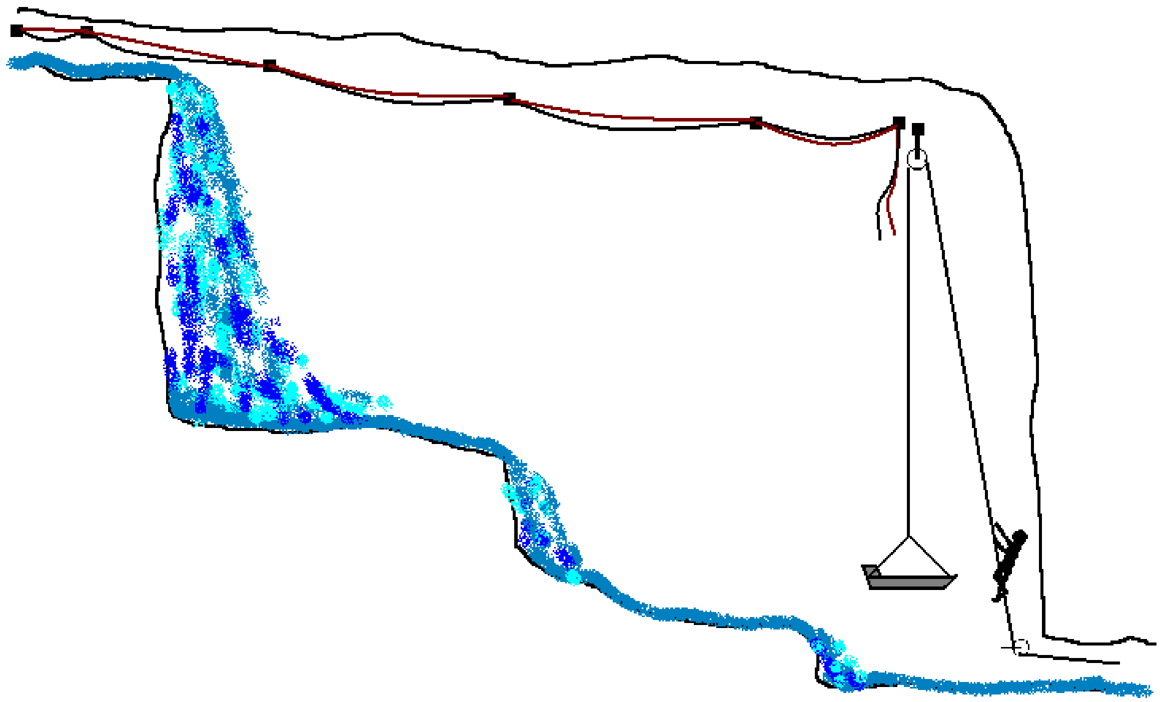
I have seen the crane jib system rigged where the dropper only extends to one bank. It’s either tied off at the traveller or starts and ends on the same bank, and pulls against the front line when in use. This is potentially highly dangerous. The front line receives high loadings from the pulley systems, and if it fails the load will whistle down and back to the foot of the bank with nothing to stop it. Cue thoughts of champagne and ships… If the dropper spans from both sides, then even a snapped tow line shouldn’t cause chaos. At most, the traveller will drift back to the centre of the traverse to await recovery.

Recovery of a traveller if either the tow or back lines break is in theory simple – you pull it back using whichever line is intact, and try again. Breakage of one of the runway lines may drop your casualty a few feet due to stretch, but is not catastrophic. The only major problem that could arise is if the traveller physically jams on the runway lines, maybe by winding up on a bit of loose rope, when the medic/barrowboy come into his own by being able to climb up to the traveller and cut things free. Pulleys rarely fail in the sense of stopping turning, and the friction involved is such that even if they did, the teams on each bank could still propel the traveller without problem. Once you have both a tow line and back line, the old James Bond scene of being trapped in mid-span is extremely hard to achieve in reality!

Traverses remain probably the most complex rigs used in underground rescue (going by the number of ropes and pulleys involved) and from experience of watching teams, especially from non-caving backgrounds, it is clear that without specific practice things can rapidly turn into chaos. More often than not during a traverse of any form, there will be times when some of the team are out of communication with the rest but still actively doing something, and pre-planning is vital to stop two groups pulling on the same rope and wondering what’s jammed.

10b. Combination pitches

The combination pitch is the nemesis of any rescue rigger. Putting it simply, it's a pitch where a traverse leads out to the start of a vertical ascent or descent, and the point of changeover has no sensible access.



In the above (terribly non-artistic) diagram a counterbalance bottom-haul is being used to raise a stretcher to the end of a long knotty traverse, trying to avoid a nasty moist cascade.

After reading all about hauling and belaying systems, and now traverses, in theory you are now armed with all the knowledge you will need to arrange a combination pitch. What you will rapidly find when trying it however is that the tiny things grow to bite you. All of your hauling rigs are designed to be easy to construct and operate provided you have 'local access' to the equipment – in a combination pitch your hauling system may have to be many metres away from the pitch itself, and yet somehow the stretcher must be transferred off and on seamlessly.

In the above scenario you should be thinking of the many other ways to achieve the aim, and the merits and pitfalls of each. Why not use a Tyrolean instead of lots of knots? Could we haul from the top of the cascade or is the horizontal path of the rope a problem? How about using a V-rig with controlling lines to raise the stretcher diagonally? Could we do something with releasable deviations? How about just going to the pub?

As a rigger, you should be thinking of all the options as you see a scenario, and going with your judgement. You may find what you planned to do won't work (lack of kit, cave that hates you, etc etc), or you may find the rules change mid-rescue (casualty arrives in a stretcher instead of walking-wounded, someone turns on the rain outside, etc etc). You must adapt without being fickle, and keep a calm overview in your head no matter how much that last option above seems to be the best!

10c. High-ratio pulley systems

This section lives somewhat separate to the other pulley-based chapters, as we are dealing here with the specific use of multiple-pulley combinations to gain high levels of mechanical advantage. A Z-rig or V-rig only multiplies the applied force by 2 or 3 times, but it is relatively easy using a handful of pulleys to rig a system that has a factor of many 10's. This has quite rare applications underground, especially in the UK, and so it is why I've hidden it away here. The problems are clear – you have to pull an absurdly large amount of rope through the device to gain a short distance on the load side, and the tensions that you can apply to the load and associated equipment can be huge.

Over the years in underground and industrial rescue I have yet to see more than a handful of applications where a pulley factor of more than 3 is required (satisfied by our humble Z-rig). Lifting a load of more than 300kg is rare, and a two-man team can adequately shift such loads using a 3:1 system. Applications where long arduous hauls are required are almost always better satisfied with a lesser-ratio system such as a Z-rig plus changes of shift on the hauling party, or ideally a winching device. The length of rope required for a large-ratio pulley system grows dramatically, and so the maximum extended length of these systems is often limited by rope to quite short sizes.

High-ratio systems do have a place in digging work though, by which I mean the movement of large boulders and so forth. If you have to move a massive rock a few inches in order to free someone, then a high-ratio pulley system comes into it's own. As the distances of rope pull are also in ratio, it is easy for a hauling team using a high-ratio pulley to control the position of a load to a high degree of precision. Provided that protection is being used to deal with a rope failure (using wooden blocks, props etc) then there is no real risk.

Calculating the load in the rope of these systems is vital, and so is the choice of components. You can easily apply several tonnes of force to the endpoints, and anchors, karabiners, pulley sheaves and rigging plates must be capable of taking the expected load. The problem is that when pulling through a 10:1 system, there is less of an intuitive 'feel' for the weight, so the rigger must work predictively. Clearly the best guess of the ultimate forces is the object being shifted – if you are trying to lift a boulder that you estimate weighs 500kg, then that is the force you have to account for. The other option is to work from the force your hauling team can apply, though this is a great deal more vague. We hinted in our opening sections that an average team member could haul (when standing) about 400N (equivalent to a 40kg load on a 1:1 ratio system). If your pulley blocks impart a 10:1 ratio, then each man can roughly impart 4kN to the endpoints, therefore lifting a 400kg load.

As you can see, even with one man, the forces on the endpoints rapidly start to creep into the figures for breaking strength of karabiners, belay plates and slings.

So how do you know the ratio of your system? You clip a bunch of pulleys to an anchor, another bunch to the load and thread the rope back and forth like a cat's-cradle, then what?
Well, the rule is that the number of ropes in between the pulleys gives the ratio. So, if you count six ropes passing back and forth between the endpoints (for which you'd need 5 pulley sheaves) then it makes a 6:1 device. If you look back at the earlier sections on V-rigs and Z-rigs you'll see it works there too… a V-rig has three active ropes in between the pulleys.

Simple logic therefore says from your ratio you can predict everything about the rigging… say you want a 10:1 system and have a 200m rope. We know that to get 10:1 you need 10 passes of rope between the pulleys, so we know the maximum length of this creation is a little under 20m, and you're going to need 9 pulleys in total. You also know that to lift a 300kg load by 1 metre, you need to pull 10 metres of rope through the rig, and that one man will happily be able to do this.

One final bit before talking safety… if you are rigging a pulley system in a muddy place, as you may well decide you wish to do, then as the ratio increases so the effort required to draw the system back out to length also increases. It takes a heck of a lot of effort to pull a 10:1 ratio system back out when the ropes and pulley sheaves are clagged in clay, so if resetting the system is going to be needed then plan how easy it will be. Never assume a dangling tackle bag will do the trick, a tail rope to a heavy-set individual with big arms is probably more in order.

The safety bit

Clearly you can go to town on ratios and make a system that will lift a small town, but you will rapidly find that karabiners are not made for this designated purpose. If your pulley system has a ratio large enough to risk overloading the components within it, then you must assume that it will fail. This is not pessimism, just common sense – in the heat of the moment with your shoring crew shouting for more lift, your hauling party cannot measure their arm strength and point out you're nearing the SWL of rigging plate 4. You therefore should allow for failure by making sure the load is controlled. If the load falling would be bad, then stop it happening using backup lines, wooden props, etc as it's lifted. If it can fall safely and you want to let it drop, then you still need to think about the pulley system itself. If an anchor fails, the tension in the lines will make the remainder of the system fly about like a snake on Viagra, so you may wish to think about protecting your team from incoming aluminium.

10d. Winching and powered aids

For industrial high-angle rescue on buildings, towers and in shafts, the notion of using a mechanical powered winch is almost universal. No self-respecting industrial rescue team would be seen without one or more of the commercial rope hoists, electric winches or capstans, and their use is increasingly looking an option to underground teams.

Sked Uni-Hoist

Winches are not a catch-all device. They are a Godsend for long pitches, surface shafts and so forth, but deep underground the classic ropework of Z-rigs and belays works far better. UK teams are also unlikely to have 10 shiny winches in their kits, but a lot of rope and pulleys!

The usual arguments against using winches are cost, proprietary equipment and the ability to cope with the conditions underground. Clearly a mains electric winch isn't an option at the foot of a complex Dales pot, but there's no reason why it can't be used for the surface shaft. Broadly therefore (at the risk of annoying manufacturers worldwide) I'm going to say that:

Powered winches are only suitable for surface-linked use

There will be nice exceptions where the power isn't a problem, but you can't rely on that. I prefer the notion that your entire rescue kit will function after being taken through a 50ft sump and will continue to function after being dried carefully in a sandbank. The options for true underground winches are limited therefore to hand-operated devices, which is actually not that limiting at all! The market is filled with rescue winches 'with a handle' and the team is left only with the issues of compatibility and pricing.

Two vital decisions on the choice of a winch are the rope capacity and ease of reset. Winches fall into two categories for live-load certified products, capstan and reeled designs. A reeled winch has a fixed length of rope or wire fitted to an axis, and it pays out and takes in this rope by spinning the axis. Examples include the Sked Uni-Hoist as shown above, which uses stainless steel wire cable and is available in a range of fixed lengths from 70ft to 300ft. Yes, you guessed it, the 300ft winch is pretty damn heavy! Also, the Uni-Hoist is only live rated to 160kg, which means it's below our limits for rescue loads. It was designed to lift either a single casualty or a single rescuer, and so should NOT be used to lift double loads. Underground rescue can make these reeled winches far less of a viable option than surface high-angle work (where they predominate), as the confined spaces and limits on cable length mean a winch is often more trouble than it's worth. In addition, reeled winches are more complex to clean – the cable has to be unrolled and washed after every 'dirty' rescue.

BMS Ropehauler

Capstan winches on the other hand take any length of rope. It is wrapped one or more times around a capstan, secured using various combinations of clamps, and the rotation of the capstan draws in the rope. The advantage of capstan winches is that the length is only limited by how much you can carry – the winch does not care. The disadvantage is that they rely on friction (reeled winches are in essence locked to the rope and friction is irrelevant) and so wet and muddy ropes can slip. Safety devices will prevent the load from falling, but raising it may be another matter entirely!

The BMS Ropehauler shown here is one of the more common capstan winches rated for live loads. It is rated to 275kg SWL and has a 12:1 gear ratio. Although securing this little beast can be fun (the 8 mounting holes in the baseplate for securing the winch to anchors are great, but to turn the handle the winch needs to be SECURE and not just tied to the wall!) it's light (6kg) and will work with any length and diameter of rope, except metal cables.

Note that the BMS has no active rope clamp, so an external device must be used.

Note 1: Man-rating or live load rating

There are literally hundreds of commercially-available winches on the market, from automotive recovery winches to sailing and building winches. However, in order to use a winch of any design for lifting humans, they MUST be certified for 'live load' or 'man rating', which means that their quality control and methods of failure are approved and safe. Under current legislation (as discussed later in this book) a rescue team may not use any winching or hauling device that is not certified and maintained according to the live load specifications. Devices intended for inanimate loads (such as are used on sailing boats) may visually look the same as rescue devices, but are not designed to fail in a safe way and are not guaranteed to the same level of minimum failure load.

There are also many industrial fall arrest devices, which look on first inspection to be similar to winches, except that they tend to have a self-retracting spring system inside them to keep the cable under tension between the winch and the load. They are specifically designed for preventing falls on industrial sites and are NOT rated for use as winches. The legal certification of 'fall arrest' and 'winching' equipment is different and to use a fall arrest system as a winch is illegal. Many fall arrest systems, if you read the small print, must be stripped down or replaced after every full loading.

Note 2: Wire and rope and bits of string

A winch, be it a capstan or a reeled type, is usually only designed to work with a specific type of rope or cable. Winches such as the Uni-Hoist for example use steel cable, while the BMS Ropehauler works only with rope. It is often physically possible to use a reeled winch with the wrong type of line, but the performance is badly affected. However, capstan winches designed for use with synthetic ropes are unsuitable for metal cables full stop. A capstan winch relies on friction between the few turns of line and the surface of the capstan, and wire cable in essence has no friction. So…

Never use wire cable in a capstan winch. Never. Ever. Ok?

10d2. Home-made winches

After all the waffle above about legal certification, you can guess that making your own winch is a tricky affair. Having said that, in the UK a lot of rescue teams and caving clubs have large-scale surface winches (often the sort of beast it takes 6 men to carry) that are powered by electric or petrol engines and used to haul caving parties in large surface shafts. The famous winch used at Gaping Gill is the best-known example, but almost all caving areas have someone who's shed houses a prized beastie.

The legal status of these types of winch is questionable to say the least. When used by a caving club and no charge or public access is permitted, then the certification and rating of the winch is reasonably irrelevant, as the users are accepting a presented known risk with prior understanding. In a rescue however, you may be lifting people (the casualty for one, and maybe medical personnel as well) who are not covered by the 'club membership' exemptions. Teams can therefore be in a sticky situation – clearly if a winch is sitting there and will greatly reduce the time of the rescue then it is in the casualty's medical interests to use it, and the risks from the winch outweigh the risks from prolonging their time to hospital. However, the team could find themselves liable if the winch upped and died mid-rescue and bounced someone off the floor. Team riggers therefore must take whatever precautions they can to ensure that the winch is NOT the 'primary supporting equipment'. That means that the person being lifted or lowered may be physically moved by the strength of the winch pulling on a rope, but their main protection against death is from a second certified rope. The simplest example is that a load being lifted should be secured to another one or two lines using running ascenders. On a descent, the same can be achieved using conventional belaying from above.

That's all, Folks!

Hopefully at this point you have all the techniques you will need for underground rope rescue. Applying them is the skill, and adapting and combining the individual systems of this book to achieve your aims. Remember, your goal as a team rigger is to convey the team down, the casualty to the surface and the team back out, all safely, rapidly and with allowance for problems on route. The most textbook-perfect system is no good in a cave that hasn't had the good courtesy to read the same book!

As with all emergency work, from cave rescue to A+E medicine to police drivers, the indication of an expert is someone who can deal with an ever-changing situation with calm, efficient progress. Panic, arguments, fiddling and discussing are fine in practices and debriefs, but on the day, you have a job to do and the lives of everyone around you depend on your abilities to apply the skills you have learnt. Do not make them wonder if you're up to it.

Cave Rescue in the UK is not run by a bunch of amateurs.
We just don't get paid.

We now delve into the associated areas of ropework, the law, care and handling, and training. Cave rescue in the UK is a volunteer service and as such relies on the expertise of the members, not only in performing the rescues but also in training and running the teams. You can't escape paperwork by going down a hole!

11. EN marking, PPE and the law

Cave rescue teams, and other 'professional care' teams using these techniques within the UK and EU are required to comply with the Personal Protective Equipment directives. There are some exceptions to the normal working health and safety regulations for rescue teams, however the fact that team members are volunteers does surprisingly little to change the legal standing of teams and the equipment and procedures they can and cannot use. At the time of writing there is still however a big question-mark over the use of equipment by rescue teams, which is one of the reasons this section of the book was delayed. Unfortunately, nothing much has changed despite the wait, so what we present here is likely to be wrong pretty soon. Rest assured that as and when things are clarified we will update the chapter!

If you are working industrially with ropes (rope access, construction, etc) then you have a rigid set of regulations to comply to. Overall, the Health and Safety at Work Act 1974 (HSAW) controls the equipment, procedures and documentation required to conduct any work-related task where there is a risk of injury. It is an 'enabling act', in that it calls on specific regulations to actually define the law. For confined spaces, that is the Confined Spaces Regulations 1997, for chemicals it's COSHH and so on. These regulations define the approval and marking of equipment and so the 'do I need a CE-marked widget and what EN standard does it comply to?' question is encompassed in this structure. If a rescue team is operating as a professional body (for example as part of the terms of employment, as some Fire Service and military teams do), then they are bound by HSAW and have to comply with it in all its details. Volunteer teams do **not** have to comply to HSAW as they are not 'at work', but there is, as always, a pitfall.

Suppose you're on a rescue, and you're all working away happily. You're all volunteers and so while you give a courteous nod to the rules, you do what works and what you're all used to. Then you find you have to call in help – be it anyone from the medical profession to a team of 50 army types with shovels. Instantly, you now have people using your gear that ARE covered by HSAW, and you're proverbially stuffed. The response is usually "ahh.. but if they agree to volunteer then it's ok". Sorry, but that's not strictly true. An employee at his job of work cannot exempt himself from HSAW even if he wants to. If he isn't legally allowed to descend a shaft on non-certified equipment then that's the way it stays, even if he signs your left arm with badger blood.

However, if you are working in **rescue**, the legislation gets horribly messy. In an effort to prevent misuse of equipment AND to ensure that existing techniques weren't instantly outlawed, the legislation exempts some parts of itself if rescue is the goal of the exercise. It is **not** important to these exemptions if the people doing the rescue are professionals or volunteers, it's the fact that it's rescue that makes the difference. This is crucially important for rescue teams, as it applies to anyone – so your army shovellers are equally exempt even if they are 'at work' while rescuing. It's not a blanket exemption from everything, but it does have some useful sidesteps for the use and certification of equipment.

Before I try and wade through these exemptions, let me walk you through the chaos that is the EN/PPE regulations. First, I guess, some idea how our laws work will help!

Before the EU, Britain used to make laws about equipment, safety and so on itself. An Act was passed defining what had to be done, and if needed a British Standard was written to define the equipment itself. So for example the Safety Widget Act 1959 would state that anyone using a Widget industrially must use one that was approved to BS 16199781. Since joining the wonderful EU, Britain has a two-tier legal system. When a new Europe-wide idea on safety is created it exists first as an EU 'Directive'. This has no legal force (you can't get sued for not following it), but then each member country passes a national law that enforces the Directive. It's this law that you can get sued for! The head-scratching can come from the next stage.. to save effort and paperwork, the new laws tend to revert to EU Directives for the technical details (like the old British Standards). You can tell it's an EU directive if the equipment is said to comply to 'BSEN xxxxxx' rather than 'BS xxxxxx'.

Since 1995, if an item of equipment complies to the Directive it can display the infamous CE mark. This must be physically printed on the object and is of the format

CE nnnn

Where nnnn is the number of the laboratory that certified the device (and NOT the EN standard it complies to). For example, Petzl equipment usually shows 'CE0197'.

The principle of this EU/EN stuff is really quite useful. If you buy a widget in the UK that's CE-marked, then it is legal to use and sell it anywhere else in the EU, without having further national stamps and labels. Before this, if you bought a German harness (DIN-stamped) then you couldn't use it in the UK unless it also has a BS stamp, even though the laws controlling these stamps were almost the same.

Anyway... on with the show…

I'm going to explain the regulations on PPE and EN standards just as if I was teaching an industrial worker, and will neglect the exemptions for rescue until the end. This is deliberate, as it is looking more and more likely that the exemptions will be reduced and incorporated so that teams will have to follow the general rules of PPE anyway. It's better to start how you mean to go on!

11a. PPE

Personal protective equipment (PPE) is, unsurprisingly, equipment designed to protect a user against a risk or hazard. In the UK it is governed by the Personal Protective Equipment (EC Directive) Regulations 1992, which are the UK implementation of the European Union Directive 89/686/EEC. It defines several things:

- What EN standards each type of PPE must comply to
- What record-keeping and marking must be used
- Training and competency of users
- Scopes of use and exemptions

The PPE regulations do not specify in detail what equipment to use. They direct the reader on principles that must be complied with, and how you do that is your affair. For example, PPE states that a device designed for ropework should be failsafe, and gives a list of the EN standards that such failsafe devices will be able to pass (e.g. a descender should comply to EN341) but would not say anything about what knot to use to rig a traverse.

Note the P on PPE – the Directive only refers to equipment to protect an individual, not property or the environment. To be specific and read you the Act, '*PPE shall mean any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards'*. General equipment such as mineshaft winches, pumps and so forth are not PPE, even if used during a rescue.

There are four (*cough* three) levels of PPE in the Directive:

0: Excluded items not controlled by PPE (such as protective devices for armed combat, self-defence and protection from the weather)
1: Simple devices to protect against minimal risk where the wearer can assess themselves the level of risk and the equipment required (such as gardening gloves, sunglasses, domestic aprons and so on)
2: Covers all PPE not in categories 0,1 or 3 (includes diving suits but not breathing apparatus) where the risks are higher but the effects can be foreseen (a diver knows he needs the suit)
3: Complex equipment designed to protect against mortal danger or dangers that may seriously and irreversibly harm the health, the immediate effects of which the user cannot identify in sufficient time.

Category 3 covers what the lay person would normally think of as 'PPE', namely respiratory devices, gas masks, heat- or fire-resistant clothing, insulating equipment for electrical work and equipment to protect against falls from a height.

Specifically, all protective equipment designed to prevent falls from a height (which means accidentally falling from a raised position OR falling while climbing using the equipment itself) is category 3 PPE, irrespective of if the equipment is designed and sold for personal or professional use. This covers industrial, sporting and rescue use of the equipment.

If an object or device is sold within the EU and falls in categories 2 or 3 of PPE, then it has to be certified. A regulated set of approvals and tests must be done to prove that the device meets the relevant EN standard, and if it does it can show the CE mark and be legally sold. Here is an interesting quirk – whilst PPE is all about using the equipment and protecting the user, CE marking is all about being able to sell something. If you go into your shed and make your own descender, then unless it's CE-certified you cannot sell it. You CAN, of course, use it yourself! In the next section I'll go through some of the EN standards that each type of equipment has to comply to, but first, let's pull up and quote the horrible exemption from the PPE Directive:

'Should rescue equipment be regarded as PPE?' is the question… and the Directive says…

If the equipment is worn before *the accident that prompts the rescue, it is PPE and covered by the Directive. If the rescuer places it on the person requiring rescue* after *the accident occurs, it is not.*

This was meant to be clear. A wet-suit worn continually to prevent hypothermia if you fall into the sea is PPE, a lifebelt thrown in to help you isn't. Unfortunately, with team-based rescue you hit a horrendous tangle of grammar. A winch used to raise a casualty to the surface after an accident is <u>not</u> PPE, but if that winch is used to lower a team member down to the casualty before they are attached, then it becomes PPE. A karabiner used to clip a casualty to a rope is not PPE, but if that same karabiner was used 15 minutes earlier to clip a traverse line to the wall, then it most certainly is!

Motto?

Anything that is not specifically designed to be used for the sole personal protection of the casualty must be considered PPE, and as such CE-marked and recorded appropriately.

11b. EN Standards

The equipment standards that a shiny new Klippenteknic SupaKlampa must comply to are defined by EN regulations, and there are a lot of them. Each regulation defines not only the equipment itself (strength, design, quality control and so on) but also the end use. So there are different regulations for using a karabiner on a boat to using a karabiner for mountaineering. Yes, there are different regulations for rescue too! As a result, a device may have more than one approval. It will be CE marked if it has one approval, but also the documentation must state all the standards it meets. It is just as illegal to use a device for a non-approved end use as it is to use a non-approved device (example – using a helmet as a hammer isn't allowed).

Some of the cave-rescue relevant EN standards are listed below.

EN 564	Mountaineering equipment : Accessory Cord
EN 565	Mountaineering equipment : Tape
EN 566	Mountaineering equipment : Slings
EN 567	Mountaineering equipment : Rope clamps
EN 569	Mountaineering equipment : Pitons
EN 892	Mountaineering Equipment : Dynamic kernmantel rope
EN 959	Mountaineering equipment : Rock anchors
EN 12275	Mountaineering equipment : Connectors (karabiners etc)
EN 12276	Mountaineering equipment : Camming devices
EN 12277	Mountaineering equipment : Harnesses
EN 12278	Mountaineering equipment : Pulleys
EN 12841	Mountaineering equipment : Descent devices
EN 12492	Mountaineering equipment : Helmets
EN 1496	Rescue equipment : rescue lifting devices
EN 1497	Rescue equipment : rescue harnesses
EN 1498	Rescue equipment : rescue loops
EN 795	Protection against falls from a height: Anchorage devices
EN 361	Protection against falls from a height: Full-body harnesses
EN 1497	Protection against falls from a height: Rescue harnesses
EN 354	Protection against falls from a height: Lanyards
EN 341	Protection against falls from a height: Descent devices
EN 362	Protection against falls from a height: Connectors (karabiners etc)
EN 353	Protection against falls from a height: Ascent devices
EN 355	Protection against falls from a height: Energy absorbers
EN 358	Harnesses?
EN 397	Protection against falls from a height: Helmets
EN 813	Protection against falls from a height: Sit-harnesses for abseiling
EN 1891	Protection against falls from a height: Low-stretch kernmantel rope

As you can see, there is a distinction between ‘falls from a height’ (FFaH) and ‘mountaineering’, which also includes rope-based sports such as vertical caving. FFaH equipment has less stringent requirements on repeated use (a device can be designed to only hold one fall and then be destroyed) whereas for mountaineering, equipment must work more than once. As you can see, the rescue equipment categories do not yet include the normal hardware of caving (anchors, ropes, ascenders and so on). This can make it fun to decide what EN standard a piece of equipment should comply to for rescue team use, though in general terms if there isn’t a specific rescue EN standard, then the mountaineering standards are considered more robust.

Note that there are a raft of EN standards for ‘lifting equipment’ such as wire rope, winches and so forth that are not intended to apply to supporting live loads. This is often a problem with devices for wire cable (u-shackles, maillion rapides and so on) where the CE mark relates to one of these industrial EN standards and not an acceptable PPE-based standard.

Now the fun part, or at least the first fun part of many. If there isn’t yet an EN standard for a particular device, the manufacturer can still CE mark it!

So long as the device meets the general requirements of the Directive (89/686) with regard to quality control, general useability, comfort, documentation and suitability for purpose, it can be certified and CE-approved even if there is no EN standard defining what it should do. As more and more EN standards are written this is less of a problem for new devices, but be aware that if you find an older device with a CE stamp it does not always mean it meets the CURRENT EN standard.

There is a saving grace though. To get a CE mark, one of the requirements is a clear and comprehensive set of instructions and performance data. From these, a competent user should be able to infer suitability for a specific end use. Any known dangerous misuse must be shown (such as threading a rope incorrectly in a descender) and guidance notes from the manufacturer on safe working practices (such as fall factors) must be given where known.

11c. Rescue exemption

At the time of writing, the situation regarding rescuers and PPE/CE is in flux. It is likely that one of two outcomes will emerge, either rescuers will be exempted from the requirements of PPE (and so be able to use non-CE-marked equipment) or a raft of rescue-specific EN standards will be written.

There are several standpoints that could be taken on the use of CE-marked equipment, but first let me make a fundamental point.

The use of non-CE-marked equipment where it exists is not an option

For example, EN 1981 covers semi-static ropes. No team in their right mind would use rope that didn’t meet EN 1891, even though that standard does not specifically talk about rescue work.

The debate only starts at the next level… if a CE-marked device intended for single-person FFaH work is used in a two-person rescue, who is liable if it breaks?

This is where we hit the debate of the Good Samaritan. It is a long-talked-about idea that in law there is this principle called the 'Good Samaritan', where if you can show you were acting in what you considered to be the best interests of the casualty then you're ok if it all goes pear-shaped. That isn't true in our case. The Good Samaritan rule (and it's only a rule, not a law) was intended for medical intervention (such as an untrained person attempting CPR). It does NOT apply to trained people applying techniques and equipment whose limitations they are aware of. So, let us take an example…

> You are using an Acme pulley as part of a hauling system, and it complies to EN 12278. Although it claims to be capable of taking the loads you are applying, EN 12278 does not specifically sanction the pulley for use in rescue. It breaks and someone decides to try and sue.

Your lawyer will of course argue that it was the only EN standard in force (there is no rescue pulley standard yet) and that your training and expertise led you to believe that it was capable of taking the load, therefore you were following 'best available protocols' in balancing the risk (it wasn't rescue-tested) and the outcome (leaving the guy to die). The other lawyer of course simply asks you:

> 'was this pulley approved for the use you applied it to?'
> 'no.'
> 'did you know this before using it?'
> 'yeah'
> 'so you were intentionally using a device unsuitable for the purpose?'
> 'err…'

and this is where it enters the unknown. As yet, no cases have been brought in the UK so we can't predict who would win. Some manufacturers are trying to help (notably Petzl and SRT) by issuing specific guidance and test results for rescue loads, basically arming your defence lawyer in advance, but until the courts make a ruling teams are on thin ice. What can you do? Well, I would love to offer you definitive help, but a very nice team of lawyers suggest that would be detrimental to my chances of freedom in later life, and so I'll word this carefully!

A rescue team not covered by the HSAW Act should wherever possible buy and use equipment in compliance with the most applicable PPE and EN standards, be those for fall from a height or mountaineering. They should comply fully with the documentation and maintenance requirements of PPE. However, a CE mark should only be taken as implying a certain quality of workmanship and NOT suitability for use in rescue. Teams should use the provided performance data, test results and instructions, together with their own expertise, in deciding the safe and appropriate use of the equipment for purposes beyond the EN standards. Where possible you should have documented arguments for such decisions available in case they are required after an accident.

11d. Inspection and paperwork

The PPE Directive not only deals with marking the equipment, it also lays down requirements for documentation during use. New items sold with a CE mark must, if applicable, have a defined service life beyond which the approval is invalid. A regular inspection process of all safety-critical equipment must be enforced and recorded.

Often this ‘inspection’ is neglected, especially in rescue teams where washing is the only thing done after the kit is returned from some squalid corner of the world. This is frankly unacceptable in the modern world, given the small amount of effort needed to comply.

Each device (from a length of rope to an ascender) should have a piece of paper on file that lists, as a minimum:

- Make and model
- Serial number or other identifying markings
- Date of purchase (and of first use if different)
- Stated lifetime from the manufacturer’s leaflets

Periodically (at a minimum every 12 months but ideally after every use, given the extreme conditions) each device should be visually inspected to a sufficient level of detail so that it can be confirmed to be functioning. For a karabiner, that may mean looking for distortion, checking the operation of the gate and lock etc., while for a rope it means a visual inspection of the entire length for stains, cuts or wear. Active devices such as descenders need to be functionally checked by operating them on a rope and making sure they lock, release etc. These inspections need to be noted on the piece of paper and dated.

If a device reaches its lifespan (either in time or number of uses) then it has to be destroyed. It is illegal for a team to sell time-expired or damaged equipment, even with a disclaimer. Some enterprising shops have been known to try and sell non-CE marked equipment by claiming they are selling them as ‘scrap metal’, but to comply with the law they should physically destroy them prior to sale so that the cannot be used as PPE.

Any device that has been overloaded or damaged should of course be retired, but I would make a specific plea to rescue teams in this respect. Equipment that has failed or been damaged by rescue operations should be returned to the manufacturer with details of the history and event, as there is far too little data returning to manufacturers on the specific problems of rescue.

An example PPE sheet is shown on the next page.

PPE RECORD SHEET WEST NORFOLK CRO

ITEM	Petzl Stop descender	Serial No.	01113
Date Purchased	15 Dec 2001		
Date of first use	25 Dec 2001		
Stated PPE Lifetime	unlimited		
Identifying Marks	Green tape on handle, stored at main HQ in locker 6		
EN Approvals	EN 341		

INSPECTION RECORD: Item to be inspected: every 6 months

Date	Inspected by	Pass condition	Notes
15/6/02	Brian Quinn	Pass	As new condition
16/12/02	John Franks	Borderline	Some wear, recheck in 2 months
10/02/03	Brian Quinn	Fail	Worn cams, fails to auto-stop

FAILURE OR WITHDRAWAL

Date: 10/02/03	**Withdrawn by:** Brian Quinn
Reason: Wear on cams, device sent for repair.	

11e. Other standards

Within the UK and EU countries, you are really governed by CE marking and EN standards, as the laws are written to only accept them. However, the older international standards such as the UIAA equipment certification scheme are still in existence, and one day may make a comeback. Specifically, equipment manufactured outside the EU and not certified under EN standards cannot be sold within the EU as PPE, however getting this approval can be expensive. For niche manufacturers working in the rescue market outside the EU, this extra expense may not be justified against sales, and so equipment that is only available from US or international suppliers may have UIAA or equivalent approvals only.

There is an exemption in force to the PPE/EN/CE rules in this respect. If an item of equipment has a recognised international standard but not a CE/EN mark, and there is no CE-marked equivalent available from another source that meets the same need, then it is permissible to use that device within the EU for rescue on the grounds of 'best equipment'. This states that equipment that offers a significant benefit and that is either not available with a CE mark, or for which there is not yet a regulating EN standard, can be used as it is in the interest of the persons being rescued to do so. It does not work to argue this for normal 'occupational' use, as there is no interest to outweigh.

There are moves afoot by organisations such as the UIAA to bring their standards into line with the similar ENs in the hope that they will become generally accepted, but this is a long process given the time for consultation and effects any change will have on manufacturers. If you know of an item of equipment that does not have CE approval, then there is nothing you, as an end-user, can do to get it. The process of obtaining a CE mark is to do with quality control and auditing at the manufacturer, and cannot be bypassed by a national distributor or user.

12. Rope testing

This is probably the most difficult chapter to write, not because of the complexity of the science, but simply due to lack of consensus on the results! Rope lifetime and age-related decay is something that the end users and manufacturers are only recently beginning to throw resources at, and the very nature of the process means that a great deal of time and work must be done before someone can write the definitive guide to 'when to chuck yer string'. We are not at that point yet, but in this chapter I will try and lay out what is known so far to be the best opinions. Remember, the text of a book is no substitute for common sense. If I say your rope will manage 2 years but yours creaks alarmingly when more than a hamster is suspended from it, then you may wish to consider yourself better informed than me!

This chapter runs on from chapter 5, which covered the physical construction and care of ropes. What we are discussing here is the specific question of how a rope performs as it gets old, and how to test the ropes you use. I stress that there is no recognised national or international standard way to test old ropes, or even a consensus on when a rope ceases to be usable. Until there is, you must rely on a combination of advice and self-testing.

12a. Working life and decay

As we have discussed in Chapter 11, the PPE regulations require that any CE-marked device (including ropes) must have a stated lifetime if such is relevant. For ropes, this means that manufacturers are legally required to give a prediction of lifetime, however they do this based on typical uses and not on rescue. For ropes, rescue places two contradicting forces on lifetime. Firstly, the ropes are on average less frequently used than those owned by sport cavers, and better cared for in terms of storage and washing. Secondly however, they are subject to far more extreme loadings when they are eventually used. The upshot of all this is of course that makers will not give quoted lifetimes for ropes used by rescue teams!

Manufacturers will quote a lifetime on all CE-marked ropes, though they do vary a lot (from 3 to 6 years in some cases). This figure is based on a notion of 'standard use', that being the normal levels of loading, washing, UV exposure and contamination that a rope is expected to suffer in use with an average owner. For non-standard uses (and rescue is one of them!) there simply isn't enough data for the manufacturers to quote revised figures. Some are quoting 'sport and industrial' figures on rope lifetimes, which assume that a sportsman uses a rope once or twice a week whereas a rope used industrially is in use at least 5 days a week, though subjected to better standards of care. For rescue we suggest using this industrial figure as a starting point, or if not quoted then subtract one year from the general stated lifetime.

Legally, a team's main priority is to comply with PPE. Therefore, if your rope says 'maximum life 5 years' then that is what it has, even if you only use it twice. There is some debate on how to deal with new ropes left in storage for many years (a rope that never leaves the reel is in essence not yet in use, and PPE has issues with that), but to be safe, if you hit the PPE lifetime then bin your string.

The process of decay in synthetic ropes is a complex one. In theory, a rope stored unused, in the dark and dry should retain it's performance forever, as the synthetic polymers do not degrade. However, they are susceptible to damage from a wide range of influences, from the abrasive action of grit through sunlight and chemicals. The result is that to a great extent the performance of a rope that has *not* been overloaded is decided by what it has been exposed to, rather than how old it is. The lifespans quoted for PPE are an attempt to define this in a way that removes the need to measure anything, but are only substitutes for a lifespan quoted in terms of sunlight, mud, chemicals, washes, wear and heat.

Several factors commonly seen during normal use are known to affect synthetic climbing ropes, and these are the main controllers of decay, in order of effect:

- Microscopic damage to core fibres from embedded grains of grit (microchafing)
- Storing for prolonged periods with tight knots
- Physical damage (cuts, abrasions and so on)
- Exposure to chemicals (acids, alkalis, detergents, fuels and solvents)
- Exposure to UV light
- Heat (through local friction burning, not ambient temperatures)

For a rescue team, adequate storage and care of ropes, as detailed in chapter 5, should not be a problem. UV exposure is often a major point of debate for *climbing* ropes. Several reams of test data have been produced on the long-term effects of UV exposure on synthetic rope materials (predominantly polyamide), but the general conclusion is that for the UK (with a UV exposure on average of 100 W/m^2) the deterioration of dyed polyamide rope and webbing is of the order of a 5% reduction in strength for a 300-hour daylight exposure. This is cumulative up to a loss of about 50% when it stabilises. Ropes or tapes using fluorescent dyes degrade faster; undyed ropes can also degrade faster as the dyes themselves often incorporate a UV-protection barrier. Caving ropes are in general not exposed to sunlight for more than a few hours each use (during packing, washing etc) and so to accumulate a 300-hour exposure would take at least 100 uses. It can be assumed therefore that UV does not have a measurable effect on ropes used solely for underground work unless they are stored for prolonged periods in direct light.

The major factor for all ropes, and in particular for caving ropes, is microchafing. Caving ropes are used in muddy conditions, and the action of devices on the rope (plus the action of cleaning equipment in many cases) serves to force the mud through the weave of the sheath. Grit particles, once embedded in the core, are impossible to remove no matter how well you wash the rope. Any grit particle that has a sharp edge can cut the thin core fibres it is in contact with, since each strand is extremely small and comparable to the range of grain sizes. Motion, bending, tension and knotting of the rope cause this individual cutting of core fibres, in effect weakening the rope every time it is used. There is no effective safeguard against this problem – climbers can keep their ropes clean, cavers cannot. There is also no physical indication that the process is occurring. You cannot see into the core, and the damage is distributed evenly through the rope so it cannot be felt. It has to be assumed that once a rope has been exposed to mud, it is on a gradual decline. Tests by Troll show that a rope can lose up to 50% of its strength from microchafing without visible signs of deterioration.

Rescue teams may like to think that they take more care of their ropes, washing them and storing them carefully, but they also demand higher performance from them. Microchafing really doesn't care how carefully you wash, how loosely you store or how cosy your kit room is, once it starts it cannot be stopped. As a result, rescue teams can be in a worse situation than occasional sport cavers using the same kit.

12b. Drop testing

The nasty bit is that you really need to know how your rope is doing. Without testing and predictive data, you cannot tell beyond visual inspection how strong your rope is, and it may well be weak enough to break after 3 or 4 years if you handle it badly. For normal sport use this is covered by the large margin of extra strength in the rope, but in rescue you often use a lot of that margin in your day-to-day loadings. Rope manufacturers are at present reluctant to release figures for their products with rescue loads, as there is insufficient commercial benefit (too few teams, too costly to do the tests). Teams are therefore left having to arrange tests of their own ropes, which in the UK is often done via the rope testing group of the NCA.

The simplest test of the strength of a rope is the drop test. Here, a length of rope is fixed between a fixed frame and a solid mass, which is raised and dropped vertically, imparting a shock load to the section of rope. By raising the mass to different heights, drops of different fall factor (FF) can be created, anywhere from 0 to 2. The number of drops and range of FFs that a rope survives before breaking is the measure of strength. Note that it is an entirely relative test – for the results to mean anything you need to perform the same tests on a sample of the rope when new, so you can see any change. Tiny alterations in the design of the test rig (diameter of securing rings, type of knot, etc etc) can change the results and so comparing data taken using different rigs is also difficult.

NOTE: Fall factors

It is important to note that a fall factor is given by the length of the rope **L** divided by the distance of the drop **D**. This is *not* the same as the total distance fallen, as the rope will stretch.

L = length between anchors before the test and with no weight on the rope.
D = distance between the release point and the exact point the rope comes under tension, *not* the furthest point it reaches.

Also worth noting (though the mathematics will remain an exercise for the reader), is that the notion of a 'fall factor' being independent of the length of rope is not strictly true unless the rope is significantly dynamic. For static ropes, the length of the rope does have an effect on the peak forces experienced during a drop test, though given the variations from other effects when doing 'DIY drop testing', it is pretty trivial. Still, it is worth using the same length of rope for all your tests.

Any rope, when new, has to pass a number of drop tests defined in the EN standard for that type of rope. For example, a semi-static rope to EN 1891 type A has to survive 5 drop tests using a 100kg mass and a fall factor of 1.0 (all 11mm ropes will be type A, type B is reserved only for 9mm ropes). There is usually a healthy safety margin, especially on 11mm ropes. New BlueWaterII+ 11mm semi-static rope can easily achieve 14 FF 1.0 falls. Some people wonder why a rope that survives one FF 1.0 fall cannot then go on to take any number more – surely if it's strong enough to take one?… well no, as always, the science of drop tests is more complex than that. Firstly, the first few drops at a set FF stretch the fibres in the rope, tightens the knots and so on, so after each drop the unloaded rope is a little bit longer. This reduces after the first few, leaving a constant length after each drop at the same FF. However, other factors come into play. Microchafing acts very powerfully during a drop test, also the frictional heating of the rope against the supports, and against itself inside a knot, starts to wear away at the local strength at specific points. Eventually the rope will fail through a combination of these effects, usually within one of the knot.

Drop tests are of far greater relevance to the true usage performance of a rope than a simple tensile strength test. Kernmantel ropes are complex systems, where the interaction of the core and sheath, and any contaminants within them, are all-important to the way a rope fails. A drop test imparts a very high force for a very short time, and replicates a fall or anchor failure. However there are many other ways a rope can fail in use (abrasion on an edge, or simple over-tensioning) and so drop tests are not a cast-iron guarantee of a rope's quality.

Note that within the UK caving community, the majority of the rope testing relates to semi-static ropes only. It is possible to apply the same types of tests to dynamic ropes, however their performance under repeated falls is a little more complex, and predicting the exact level of decay (and working life left) is substantially more difficult. The EN standard for dynamic ropes (EN 892) uses drop tests plus other factors to specify approval, however the critical factor in dynamic ropes tends to be not the ultimate strength but the peak impact force created during a fall, and how that changes on subsequent drops.

12b1. Mechanisms of failure

There is a lot as yet unknown about the way a rope fails under a drop test. Several things are known, and several old myths are beginning to be disproved.

MYTHS

1. *A rope running over a corner fails due to the changes in tension on the rope around the bend. (the so-called phonebook effect)*

This is based on the performance of laid ropes, where the tension in the lay strand on the outside of the bend is larger than the others as it is pulled around a longer distance. The rope tears (like a phonebook being ripped page by page) rather than snaps, however in kernmantel ropes this effect is dramatically reduced as the cross-sectional profile of the rope can distort into a flattened oval. With corner radii large enough not to count as a knife-edge (and so impart a cutting action) failure at a corner is not normally due to this phonebook effect, and is usually the result of frictional heating of the rope as it moved across the corner surface.

2. *A rope that holds the biggest fall factor is the strongest.*

This is a play on semantics. The FF decides the energy imparted to the rope ($E=\frac{1}{2}mv^2$) and not the peak tension in the rope – that depends on the energy *and* the stretch in the rope. It's equivalent to saying that the first 10mm of a brick wall will stop a car, but so will 50 feet of Styrofoam. A rope that stretches more under load will dissipate the energy more gradually, and tend to survive higher fall factors, even if it's tensile strength (the slow steady pull needed to snap it) is smaller. For rescue semi-static ropes, riggers will often prefer a rope with less dynamic stretch (as it plays havoc with your rigging) at the expense of less protection against high fall factors.

3. *A fluffy rope is a weak rope*

With natural fibre ropes, wear that caused broken strands (fluffiness) seriously weakened the strength, as the rope's performance relied totally on the frictional forces between strands. Modern kernmantel ropes based on synthetic fibres are a great deal more resistant to individual fibre damage on the sheath. In a high dynamic loading situation, the function of the sheath is partly to add strength, but mainly to act in compression on the core, forcing the core strands together and increasing their mutual friction. Generalised damage to the sheath fibres (fluffiness) does not affect this constricting process, and tested ropes with fluffy sheathes often show little or no loss of drop-test strength over unworn sections. What is significant is a localised point of damage where a large number of the sheath fibres are cut at the same location; this can lead to a tearing effect in the sheath. Obviously, damaged core fibres under any circumstances are significant.

KNOWN FACTORS

1. Friction and compression inside knots

In a large majority of drop tests the rope will fail at a point inside the knot, rather than in mid-span or at the point the rope is looped around the fixings. This seems to be due to a combination of the friction caused by the knot moving over itself under shock loading, and the compression of the rope by the turns of the knot. It does not seem that the exact point of failure is the section within the knot of maximum curvature, rather it seems to be the point where the exiting rope is crossed by the last loop of the knot (assuming a figure-8 or figure-9 knot).

2. Water

The results for drop tests are significantly poorer when the rope is wet, in particular when the rope is soaked and irrigated as in the NCA test. Physically, the presence of water should reduce inter-strand friction and increase the performance, however chemically, the water is absorbed by the synthetic molecules (polyamide, a.k.a. Nylon, is particularly good at absorbing water) and serves to weaken the chemical bond strength within the strands themselves. The result is that a water-soaked polyamide rope can be 10 to 15 percent weaker than a dry rope from the same reel.

3. Temperature

Normally, drop tests are performed outside due to the physical size and action of the test rig, so temperature is not a significant factor. However, data from other countries shows that drop test results are slightly affected by large changes in ambient temperature (for example from just above freezing to 30C).

4. Integrity of the load mass

It is vital to the drop test that the force is applied from a totally rigid moving mass to another totally rigid fixed anchor. If the test rig frame is at all pliable and the anchor point can move under the shock then the test results show an erroneously strong rope. Similarly, if your test mass is not a solid object (you for example use a bundle of chain instead of a block of concrete) then the force applied by the mass as it falls is spread out in time slightly. This in turn reduces the peak force on the rope and makes the rope strength seem better than it really is.

Aside: The mathematics of drop testing, kiddies version

From the initial viewpoint the physics and maths of a drop test seems trivial – you let a mass fall, it converts potential energy to kinetic, and this is then transferred to a rope which acts like a long floppy spring, stopping the mass and stretching in the process. On a general level this is indeed true, however for semi-static ropes the simple idea that the rope is a spring doesn't hold true.

If we were to assume that our rope behaves like a simple elastic spring (stretch exactly proportional to load applied, just like a rubber band) then the peak impact force on the rope will be when the rope is at maximum stretch. Some simple juggling with the equations for potential energy and spring energy will therefore show that:

$$I = mg\left(1 + \sqrt{1 + \frac{2FK}{mg}}\right)$$

where:

I = peak force, m = mass of falling body, g = gravitational constant (9.81 ms^{-2}), F = fall factor and K = modulus of elasticity, a.k.a. the (force per unit length per unit length)

K is tricky to find in manufacturer's data, so we can rewrite the equation using something that we can measure: *s* , which is the percent stretch in the rope when the mass *m* is hung on it. We get:

$$I = mg\left(1 + \sqrt{1 + \frac{2F}{s}}\right)$$

Firstly let us try the equation (before we write it off as simplistic) using an 80kg mass and a percentage stretch of 3%, which is probably a bit excessive for 11mm semi-static rope…

Fall factor (F)	Peak force (I)
0.25	4.1 kN
0.5	5.4 kN
0.75	6.5 kN
1.0	7.4 kN

Now let us try again, using 200kg and a stretch of 7%:

Fall factor (F)	Peak force (I)
0.25	7.7 kN
0.5	9.8 kN
0.75	11.4 kN
1.0	12.9 kN

The numbers seem a bit small, since 200kg is more than twice 80kg and yet the forces are less than twice the values above. However, our equation takes in the fact that a larger mass makes the rope stretch further and so the energy is dissipated over a longer time, making the peak value less than you may expect. Having said that, forces over 8kN are not to be sneezed at!

The calculations above make two critical assumptions that mean we can't expect those forces to be present in a real drop-test:

1. Some energy is dissipated in tightening knots and in non-elastic effects inside the rope, making the peak force smaller, especially on the first drop.
2. Repeated drop tests reduce the elasticity of the rope (decrease *s*) and so the peak force rises after each drop.

The result is that the rope experiences different forces on every test, and for semi-static ropes where *s* is small, the non-elastic effects are significant and can even dominate. This change in peak force also helps to explain why a rope will break after a long repeated set of 'identical' drops – as the forces are far from identical!

The only reliable way to obtain the peak force during a drop test is to measure it. Many people have tried to improve on the simple equation above, but to put it simply; the rope is too complex to let itself be written down in an equation!

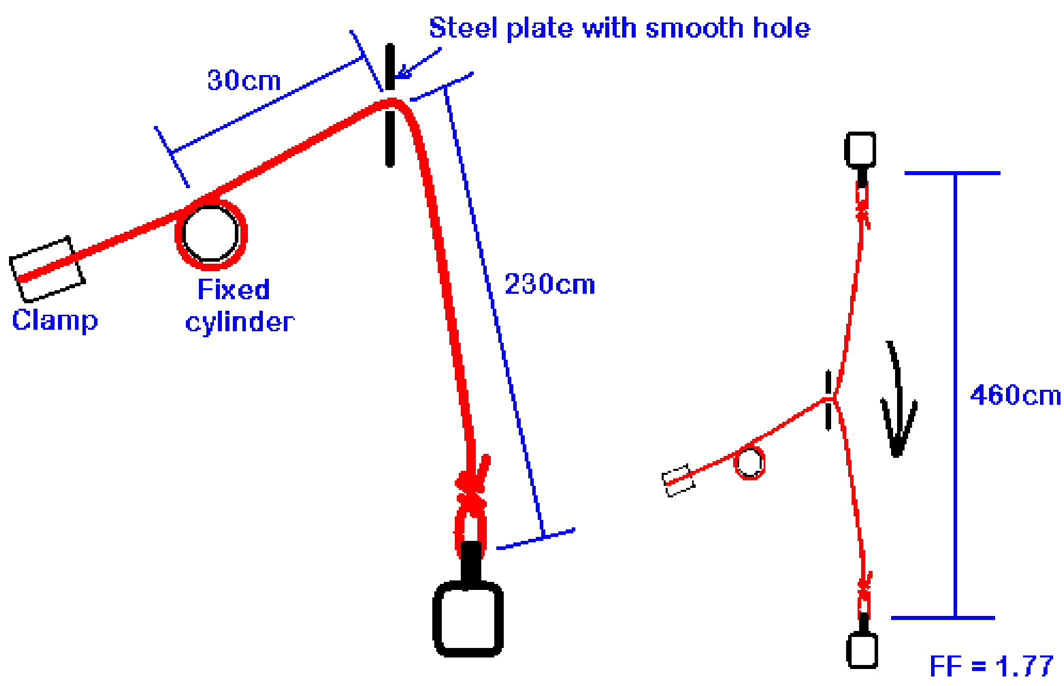
A little note on the construction of drop test rigs

The majority of home-built drop test rigs are based on a solid mass raised by some winching system and released, with the rope tied between this mass and a fixed ring or peg mounted above it. This works fine for fall factors less than 1.0, but to achieve FFs greater than that, the mass must be released from a point *above* the fixed anchor. There is a problem with this of course – you need the mass to fall vertically and for the rope to be vertical also, hence it seems the mass needs to pass through the tope anchor as it falls! A lot of test rigs (including the NCA device) offset the anchor just enough to let the mass fall past it, but therefore impart a horizontal component to the forces.

There is however no reason why the mass needs to be connected in any way to the rope until the point at which the force is applied – i.e. when the mass reaches the bottom of the fall. Petzl and a few other manufacturers have designed their test rigs to use this principle in a design called a 'catch plate rig'. Here, the rope is hung vertically between a framework of vertical guides, and on the bottom of the rope is a light but strong plate or bar, called the catcher. The mass is unconnected to this bar, but instead moves freely within the confines of these guides (usually two u-channels, or two round bars). The catcher is designed so that as the mass falls past it, it is hit and dragged down, thus transferring the force to the rope. The big advantage of this catch plate design is that you can apply fall factors of any value – including values greater than 2. There is no horizontal force on the rope, and the mass is safely contained by the guides. The disadvantage is engineering – the mass must move without friction as it falls, so bearings and careful shaping of the rig and mass are needed – plus a bit of thought into the catch plate. The falling mass must of course clear the rope itself as it falls, and so a common design has a round or square mass with a large central hole, inside which the rope is hung. The catch plate in that case is just a bar or plate slightly bigger than this hole, so the mass hits it and drags it down.

Another point to note is the exact design of the rig can be quite variable. In the BS/EN test the rig shown as an example ties the rope to the falling mass using a figure-8 knot, but the anchored end is not knotted, instead it passes several times around a large cylinder then the tail is clamped in a vice. This allegedly makes sure that the only knot to be tested is the one at the moving end, but it has questionable effects on the data compared to the normal 'between two knots' designs. Also, the rope passes over an edge in the BS/EN design, simulating a fall where the mid-point of the rope is held on a running belay, such as with a lead climber fall. Normal drop test rigs do not incorporate this modification, as it is difficult to engineer cheaply and reliably. Personally, I would suggest that for testing of semi-static rescue/caving ropes the straight-line test is more relevant to real-world events, since falls on running belays are very unlikely using these types of rope.

The older UIAA drop test uses the same idea of a rope falling over an edge – in this case a karabiner. A 2.8m length of rope is clamped at one end, run around a fixed clynder then through a 'karabiner' 30cm away, and the resulting 2.3m of rope used to create a 4.6m length-of-fall for an 80kg or 55kg block. This makes a fall factor of 1.77 and the UIAA tests define how many falls a rope should take and the peak force on the rope during each fall. Again, it is engineered to simulate falls in climbing, not in caving and rescue work, where the more common 'fall' is a short drop of a very heavy object with the force applied directly to the anchors. You can argue that 'directly to the anchors' is rare, but in rescue we deviate ropes using pulleys – so there is trivial loss of energy in friction.



Drop test rig used for UIAA and EN892 tests

12b2. The NCA Drop test

The NCA in the UK has a programme of rope drop-testing for semi-static caving ropes, using a purpose-built rig that is owned and operated by the NCA. It will test ropes sent to it from anywhere in the UK. The NCA test uses a sequence of five drop-tests using a 100kg mass and a length of rope knotted using two figure-8 loops. The rope is soaked in water for at least 2 hours and tested immediately, while still wet. This is meant to reproduce caving conditions. The rope is a short length running directly between a frame and the load with no intermediate edge as for the EN tests.

The five drops use fall factors of 1.0, 1.0, 1.1, 1,2 and 1.3 with a 'pass' condition being failure on or after the third drop.

This exceeds the EN1891 standard (of five FF 1.0 drops using 100kg) so that the rope is likely to fail during the test. If all the ropes passed the test then predicting decay would be more difficult, so the NCA test deliberately exceeds the original standard in an attempt to force failure. It therefore does not reflect a rope's approval under the EN standard, though normally brand new ropes made to EN 1891 type A will survive at least the first four drops.

Data on the ropes tested is collated by the NCA and it is hoped to be of benefit for predictive work in the future.

12b3. The LOAL rescue drop test

This test system is designed specifically for semi-static rescue ropes and will not be of use for normal caving ropes of less than 11mm diameter, or dynamic ropes. It is designed to be a compromise between the EN standard for testing, and the loads seen in rescue work. The principle is that for rescue ropes the loads are higher, but in general the fall factors expected are smaller.

The test is performed on a wet rope, soaked for at least 2 hours as for the NCA test. A length of rope is tied into a single span between figure-9 knots so that under tension of 70kg the knots reach between points 100cm apart. The knots are secured to a fixed frame and to the falling load, which should be a 200kg mass.

The following set of drops is performed:

1. Static hang of the load from the rope with no fall, to tension the knots. The length between knots is measured at this point.
2. FF 0.25
3. FF 0.25
4. FF 0.5
5. FF 0.75
6. FF 1.0 repeated until failure

After each drop the length between knots is recorded.

Ideally a serviceable 11mm rope should retain enough strength to pass drop test 4 or 5. Given the uses of semi-static ropes with rescue loads, we know already that a drop of fall factor greater than 0.5 will be assumed to cause failure of all the associated equipment (anchors, pulleys, karabiners etc) and so that is the serviceable criteria which I propose for the test. However, until data starts coming back to me on ropes and results it is too early to say if this proposed pass/fail level is realistic.

One advantage of the LOAL sequence in terms of practicality of course is that the fall factors do not exceed 1.0, so a catch-plate test rig or something similar is not required. I must say for the benefit of all the lawyers who are waking up at this point, that neither the NCA nor the LOAL test sequence claim in any way to reproduce or compare to the stated requirements of the BS/EN standards. For that, you must do 5 unity fall factors with a 100kg mass – no more, no less, no cheating.

12b4. The before and after

Once you have found out where to send your rope samples for testing, or built your test rig, then choosing the rope samples should not be a random affair. There is a major implication to volunteer rescue teams in drop testing – that to test a rope you need to cut off a section, hence drop tests gradually destroy your rope inch-by-inch. However, hopefully drop tests are at most a yearly event, so if your rope has an expected lifetime of 2 to 3 years, it can afford to be a few metres shorter every Xmas.

Many people find out that the tester has asked for a 2m sample of rope, so cut 2m off the end of their rope and send it in. This is simply silly – that last section of your rope has had far less use than the rest of it – you KNOW not to tie off anchors with the last few inches, and for most of your callouts at least 10 metres stayed in the tackle bag. On average, the most abused section of a semi-static caving rope is the section between 1 and 4 metres in from the end. This is the section that receives all the rigging knots, also it is where SRT devices are fitted and removed, which can damage the rope through the action of toothed cams and so on. This is therefore the area of the rope that you most want to test – if this passes then the rest should be stronger. I suggest therefore that the policy for taking a drop-test sample is to cut back a 1m length, *then* take your sample for the tests.

You of course will make sure that both the sample and the freshly-shortened rope are relabelled correctly and the change in length recorded on the PPE sheet, lest someone on a descent question your lineage when a 50m pitch is not adequately spanned by your new 47m rope.
The ultimate question however is what to do with the rope when the results come back. No home-designed test (or even the two tests described earlier) will give you a legally-binding yes/no to your question of the rope's lifetime. Hopefully as the years pass, more and more data will be collated on drop tests, and a better idea of the way they relate to the PPE regulations will emerge. In the meantime, all we can say is that if a sample of rope shows a significant loss in performance compared to a sample of the same rope when new, you must clearly have to question the continued use of the rope by your team. If you have the funds or connections to replace ropes with great regularity, you may not even want to bother doing drop tests, instead choosing to replace your ropes every year or two without debate. However, I would ask that teams retiring well-used ropes without needing a drop test would be helping the work of the NCA and others a great deal by sending a sample in for testing anyway – to bolster the databases. If you have accurate usage data on a rope then often the manufacturer themselves

will appreciate a few metres posted back to them for testing, since rescue teams are considered reliable when they give usage data when perhaps individuals and sportsmen are not.

12c. Other tests

Drop tests are the simplest and quickest way for an 'amateur' to get an idea of the strength of a rope, however there are many other ways to collect data if you have the equipment, time and/or enthusiasm. The problem is that apart from data collated by the rope manufacturers, few people are measuring anything other than drop test results, so the potential benefit of other data in predicting strength and lifespan is as yet unknown. These include:

- Tensile strength pull-tests (straight or knotted rope)
- Elongation under load
- Peak impact force measurements in drop tests
- Cyclic bending tests
- Drop tests over a sharp edge

A lot of these tests require access to measuring equipment (dynamometers and so forth), and their data is not of direct benefit to rope owners, so they are not viable except for research. However, specific effects can be more accurately measured using some of these tests (such as the slight reduction in tensile strength due to chemical exposure), where drop tests add too much complexity. A drop test applies many stresses to a rope, from the energy of the fall to the compression of the knot and the pressure-wave effects of water within the core, and so often the rope fails, but for an unclear reason. Ropes are complex pieces of mechanical engineering, with far more moving parts and interacting factors than the devices they are used with. The way they age, and the reasons they fail, are often a mystery that only time and the collection of hundreds of test results will explain.

12d. The specifications for rope

Whilst not of direct relevance you may like to know the specifications used by the two EN standards for kernmantel rope.

Semi-static ropes comply with EN 1891, and can be issued with one of two type codes. Type A ropes are the norm, and apply to all ropes greater than 9.5mm diameter. Type B ropes (9.5mm and less) are of a lower performance and are specifically intended for use by people using extra care and precautions. They need greater protection from damage as the safety margins are lower, however they are still capable of taking human loadings safely.

Test parameters for EN 1891	Limit for type A	Limit for type B
Shock force, F The peak force transmitted to an anchor point during a fall factor 0.3 with a mass of M kg shall not exceed 6kN	M = 100kg	M = 80kg
Number of falls, N Using a 2m length of rope tied with figure-8 loops on a rig producing fall factor 1.0 drops, the rope must survive five or more falls at intervals of 3 minutes using a mass of M kg.	M = 100kg	M = 80kg
Elongation, E The percentage change in length of an unknotted sample of rope which occurs between loads of 50kg and 150kg	E <= 5%	
Knotability, K A single overhand knot is tensioned with a 10kg force for one minute. The force is reduced to 1kg and the internal diameter of the knot measured. K is this internal diameter divided by the diameter of the rope	K < 1.2	
Sheath slippage, S A 2m length of the rope is drawn through a pulling rig (a constriction specified in the EN document) 5 times. The slippage of the sheath is recorded in mm.	S <= (10D – 180) where D = rope diameter	S <= 15
Sheath ratio, M The mass of the sheath divided by the total mass of the rope	30% < M < 50%	
Static strength, T The breaking force of an unknotted rope in clamps	T > 22kN	T > 18kN
Knotted static strength, Tk The breaking force of a length of rope tied with two figure-8 knots and under tension for 3 minutes	Tk > 15kN	Tk > 12kN

The EN standard also requires that the rope contain an internal identification filament or ribbon that shows by colour code the year of manufacture. Each end of a new rope must be marked with the name of manufacturer, type of rope (A or B), diameter, CE mark and EN number and the identifier of the test house approving the rope. Some manufacturers also print this data on the internal ribbon, but that is not part of the CE specification.
There is another EN standard, EN564, which refers to ‘accessory cord’. This has been used by some manufacturers on specialist ropes of less than 9mm but has no bearing for rescue.

EN892 covers dynamic kernmantel ropes. Although it lives in the ‘mountaineering equipment’ section of the EN structure rather than the ‘falls from a height’ section, the requirements are very similar. There are two main classes of rope in the standard, ‘full ropes’ and ‘half ropes’. A half rope (marked ½ on the ends) is of lower performance and is intended for use doubled-up. Full ropes (marked ‘1’ on the ends) can be used on their own. Some people refer to the classes as ‘single’ and ‘double’ ropes, but this is to be avoided. Obviously for rescue work only full ropes are suitable. There are also newer classes of rope – ‘double’ and ‘walking’ ropes have lower standards again, and their intended uses are limited.

There are also many variants on dynamic ropes beyond the EN892 specification. 'Gym ropes' are engineered to be more robust near the ends, others have special coatings and treatments to make them slippier, less water-absorbent and so on. All must eventually pass the EN tests however, and these optional add-ons are not yet included in the standards.

Test parameters for EN892	Limit for type A	Limit for type B
Shock force, F The peak force transmitted to an anchor point during a fall factor 1.77 with a mass of M kg shall not exceed F kN. The test uses the UIAA drop rig.	M = 80kg F < 12kN	M = 55kg F < 8 kN
Dynamic elongation, D The peak extension recorded in the first drop test in the test above for shock loading	D < 40%	
Number of falls, N Using a the same rig for shock force, the rope must survive five or more falls at intervals of 3 minutes using a mass of M kg.	M = 80kg	M = 55kg
Elongation, E The percentage change in length of an unknotted sample of rope which occurs with a load of 80kg	E <= 8%	E <= 10%
Knotability, K A single overhand knot is tensioned with a 10kg force for one minute. The force is reduced to 1kg and the internal diameter of the knot measured. K is this internal diameter divided by the diameter of the rope	K < 1.1	
Sheath slippage, S A 2m length of the rope is drawn through a pulling rig (a constriction specified in the EN document) 5 times. The slippage of the sheath is recorded in mm.	S <= 40mm (or 2%)	

Under the EN892 specifications, there are no specific limits for the static strength of the rope. This is the main reason why drop-testing is used by most programmes to research the ageing of ropes, since for EN892 ropes the other factors are often unknown. The UIAA specification is the same as above except for a change to the slippage S, making it 20mm rather than 40mm. As a result almost all dynamic ropes are manufactured to comply to both EN/CE and UIAA approvals.

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13. Contamination and disinfection

This is a new idea, and has not been a part of a 'caving' book before, though is a common topic in the medical field. The common-issue British caver is recognised worldwide for the sallow expression caused by years of engrained silt and mud, and would never be seen dead sporting equipment that isn't worn to a claggy brown by years of isolation from any form of detergent. This is all well and good, but the rescue team equipment officer, every now and then, gets a hank of rope to wash that's more of a red colour courtesy of the remains of the person they just recovered. Washing and disinfecting team kit can be more of a challenge than just dunking it in water like the usual caver would do, as many of the procedures to remove infectious hazards from equipment are also likely to damage the strength and lifetime of ropes and slings. Within the UK in 2001, the national outbreak of Foot and Mouth disease also awoke questions on what to do with team equipment that has been used in a 'contaminated area' where there may be legal requirements on cleaning that contradict care instructions.

13a. Overview

'Contamination' in this chapter refers specifically to materials present on ropes and equipment that do not in themselves present a direct risk to the equipment, but may present a health risk to the user. If your equipment is exposed to solvents or acids then it is likely to be damaged even if you wash it afterwards, and the continued use of that equipment would be irresponsible. However, biological materials (body fluids, infectious agents and so on) can leave equipment undamaged but dangerous. 'Disinfection' is the specific term to describe the treatment of equipment to remove the risk of infection. This is subtly different to decontamination – you can disinfect something by killing the bacteria or viruses on it but without washing them off. Decontamination is the process of removing the harmful substances with or without killing anything.

Provided that they can be removed safely, the equipment can be returned to use. The word of importance of course is 'safely' – cleaning agents can be just as destructive to ropes and harnesses as any other chemicals, so it is vital to ensure that how you clean does not affect the equipment.

The non-biological forms of decontamination, including removal of chemicals and radioactive particles, will not be considered in this chapter. Within the cave rescue community it is unlikely that equipment will be exposed to these risks except in extremely rare accidental circumstances. Teams are not trained to handle 'hazmat' incidents and so would never be called on to intentionally expose themselves or their kit to such contaminants. In the rare event of an accidental exposure that only comes to light after the team are on scene, it would be expected that any contaminated equipment would be impounded by the regulatory agencies. We will instead concentrate on biomedical contamination from the casualty or from the environment (as in Foot and Mouth).

In medicine there are two types of disinfection – containment and reuse. Containment disinfection is done to prevent the spread of a hazard (for example washing equipment before removing it) from a localised site of contamination, known as a hot zone. Reuse disinfection is to clean the equipment to the point it can be reused in safety. Containment disinfection is often limited by the facilities available and the needs of the situation, whereas reuse disinfection can be a more considered and complex process. Obviously, processes that require the items to be taken to a facility (pressure autoclaving or irradiation) are not options for containment.

For a rescue team there are only specific circumstances where containment disinfection is required. Some we have already experienced in the UK (such as the F&MD outbreak), others (such as biochemical accidents or terrorist acts) have not.
In many cases of a hot zone the statutory agencies in supervision will have standing orders on the methods of disinfection and decontamination. This applied in the F&MD outbreak when a list of approved disinfectants and dilutions was issued. This list unfortunately was incompatible with the materials in rope rescue equipment, and this in part led to the decisions imposed restricting the response of UK teams to farm sites. Luckily, there was an equally universal closure of sport caving, so there were no callouts to restricted farms. If the situation arises in the future and a standing order list is issued, then it is likely that any equipment used on an infected site would have to be quarantined or disposed of. National guidelines should be issued by the BCRC in the event of a national outbreak.

13b. Biomedical disinfection

This leaves the main risk of biological contamination from a casualty, in terms of blood and other body fluids. The obvious risks presented are twofold – does the body fluid present an infection risk to people using the equipment in future, and is it capable in itself of damaging the equipment?

Body fluids, with the possible exception of vomit due to its acidity, present no structural risk to metallic or rigid plastic equipment beyond the simple ability to clog up working parts.

Tests outlined in section 2a2 noted that both blood and urine could have a detrimental effect on the strength of nylon and polypropylene fibres, although blood only has a minor effect. Vomit, by the fact that it is acidic, is also detrimental to nylon but less so to polypropylene. There is clearly an issue of cleaning the equipment as soon as possible to prevent any chemically induced damage, but if ropes or webbing were left for prolonged periods without being cleaned, then you would be well advised to consider them unserviceable.

Body tissues picked up during a rescue will usually be contaminated by blood, but the tissue itself presents no risk to the integrity of ropes and webbing. Body tissues can however be very hard to clean if left to desiccate, in particular brain tissue. There is a specific question on decontamination of items exposed to brain tissue as the infectivity with respect to prion diseases (CJD etc) is not yet fully understood. However, the direct risk from prion diseases is only significant from direct surgical contact with previously contaminated equipment, which would be unlikely with rescue equipment, possibly excepting protective headgear used by a team on casualties.

In terms of infection risk to subsequent users (both during the rescue and during cleaning), then blood, faeces and to a limited extent vomit are capable of transferring infectious pathogens. Urine is sterile on production and presents no biological risk.

As an aside, none of the current BCRC-approved medications present a material risk to rescue equipment.

13c. Cleaning agents

There are obviously two categories of equipment to deal with. Metallic or plastic components can be cleaned using more aggressive chemicals than fibres and ropes.

Under the terms of the PPE Directive (Annex 2, section 1.4) all equipment must be supplied with information on cleaning and disinfection. The response to this is often limited to the bare minimum, as manufacturers are rightly reluctant to suggest exposing their equipment to any aggressive chemicals if at all possible. Many either state 'washing in warm water' or using a diluted solution of 'compatible disinfectant' without stating what that may be. Legally, a manufacturer has to provide such information on request to enable a user to satisfy their obligations to disinfect equipment, and so the rule seems to be to ask first and wash later!

Some general guidelines are however known, based on the data issued by some more forthcoming manufacturers and extrapolated based on the known composition of their products. The old-fashioned universal disinfecting agent was to soak for at least an hour in a 1% solution of hypochlorite bleach in water, however this is alkaline and presents a small risk to all synthetic yarns, especially if used to soak the material for a long time. It is certainly suitable for any metallic equipment, although is rarely suggested by manufacturers in case the dilution is used incorrectly. One trick from the EMS field when using a bleach solution to disinfect fabrics is to alternate 5-minute soaks with rinses, as it helps prevent the protein in blood denaturing and making a permanent stain.

Modern disinfectants are usually based on ammonium compounds mixed with a chlorohexidine solution. When diluted to working strength these are reasonably pH-neutral, and so present little risk to either metallic or woven equipment. DMM, amongst others, recommends using a lukewarm water solution (20C or less) of a generic disinfectant (such as Savlon) for treating their harnesses and equipment, by soaking for an hour then rinsing thoroughly in lukewarm water. They specifically state that the washing and rinsing solutions must lie within the pH range 5.5 to 8.5.

Petzl, on the other hand, show a graphical recommendation in their product instruction manuals of an aqueous ethanol solution at 30C, again soaked for an hour. This applies to all their products including harnesses, mechanical devices and helmets. Polypropylene is resistant to ethanol, however nylon is not. The ethanol solution must be rinsed off thoroughly. However, a statement issued by the Petzl technical engineers in March 2003 states:

'Petzl… no longer recommend the use of ethanol… Disinfection should be by soaking in plain water at 30 degrees C for one hour then rinsing in plain water'

We are awaiting more useful information from Petzl, following our reply that soaking in water is not, to the best of our knowledge, a recognised method of disinfecting anything that is not already sterile. Petzl claim that their change of position on ethanol is due to the complexities of dilution. It goes to show that whilst manufacturers have a duty under the PPE Directive, they seem reluctant to keep to it. Rest assured that as soon as someone in Petzl makes a move, we will update this page!

One thing to note about disinfection through soaking – you may not actually make the equipment look any cleaner unless you scrub it too – but it will be biologically safe. Once disinfected, a normal washing process should be used to spruce up any marks, if only for visual effect. Whenever a mechanical device has been disinfected, you may of course have to re-grease the internal parts in accordance with the manufacturer's guidance.

Ultimately, before applying any chemicals to an item of safety/PPE equipment you should take reasonable steps to ensure that it is not going to harm it in any way. This usually is (and until they release data up front will continue to be) via contacting the manufacturer directly and telling them the product and nature of the contamination you wish to remove. However, this is plainly an unacceptable way of working, as replies can take weeks, during which your equipment is unusable. As we have said, some biological contaminants can have a detrimental physical effect on fabrics and yarns, so we suggest that while you await advice from a man behind a desk somewhere on the other side of the world, you wash the item normally to remove as much as possible of the offending contaminant, lest it reduce your expensive equipment to scrap while your case is considered and coffee is drunk.

Above all, please remember that the safety of your team and your casualties, both in terms of the strength of your equipment and any risks it may present from contamination, is never worth the cost of replacing it. If, of course, you have to replace an item then you may wish to consider the ease of disinfection, or the ease of obtaining help with disinfection, as part of your process of choosing a new supplier.

14. Training for rescue teams

This chapter will undoubtedly raise the hackles of cave rescue team stalwarts across the country, who will point out that (a) I claimed that this was not a training manual, and (b) that they are doing just fine thank you without being told how to teach someone to knot string.

Well fine on both counts, I am not in a position within the pages of a book to teach caving skills, teamwork or the routes through your local haunts – however a great number of rescue teams in the UK have little or no crossover to industrial (I will avoid using the term ‘professional’ to save getting beaten up) teams and training. Historically, rescue teams learnt by taking experienced cavers and making them attend practices and callouts until they inherited the skills they needed from a combination of watching and trying, akin to my medical methodology of SODOTO (see one, do one, teach one). This has merits of course, but it is pretty inefficient. Suppose you were to learn to drive entirely by hanging around with your mates – you could pick it up sure enough, but would you pass the theory test?

What I intend to do in this chapter is show some of the training techniques used for industrial teams (including the armed forces and Fire Service) and how they could be applied to helping create better skill bases in a volunteer team. None of what I say is gospel, and you are perfectly free to put down the book at this point and carry on as you have been. However, if you feel like expanding your methods a bit, or you are on the cutting edge of teaching and want to see if you can catch me out, then read on… there will be a test at the end of the semester.

14a. Training riggers

The rigger is the heart of the team in terms of ropework. In a typical UK team callout structure, they rarely figure. The typical structure is:

1. Team controller (usually also the surface controller)
2. Underground controller or captain
3. Pitch captains
4. Groups and individuals

I omit medical specialities as that is, I hope, a separate structure on your callout. The medic needs to be devoted to the casualties and not burdened with other roles. Also, whatever the medic says goes if it bears on the care of the casualty.

In the above structure, levels 2 and 3 would need to be riggers, the man at level 1 need not be but an overall skills base is vital to efficiently manage his team. Within reason, people at level 4 need only to be able to follow directions and perform self-progression.

A different structure, based on the military system, is to have levels 3 and 4 replaced by independent groups each including (and headed by) a rigger, and able to operate on any task they are assigned. A team of say 3 people could be told to rig a traverse, search a lower series or lay in the telephones, and they would do the job without further instruction. This makes the underground controller independent of the technical details of the rescue – he may decide the route to be taken, but the ropes and anchors used are dealt with by the groups. This is all nice and efficient and adaptable, but it requires that a rigger running a team can achieve pretty much anything as long as he is given the equipment. This is where rigger training comes in – riggers should be able to accomplish anything in this book, plus all the intricacies of normal self-progression (by which I mean moving personally through the environment using SRT or other methods). They need to be able to improvise and make decisions on the routes and rigs they construct in advance of the casualty arriving, so they need some appreciation of stretcher handling too.

I am not implying that a rigger is some all-knowing being that can rescue someone single-handed while rousing guitar music plays and credits roll. There are many things that a rigger does not need to know at all – such as the system he is in. As long as one person in the group knows the routes and anchors, the rigger can consult them for help. He does not need to be a medic – ideally someone else in the group should be, but he needs only to understand about how to handle the team's stretchers.

Above all, a rigger needs to have a 'rescue brain'. This is something that you can only teach by specific practice and training, since it often contradicts their personal brain:

A personal brain is presented with an obstacle and thinks of how he would get past it, using his skills as a caver

A rescue brain presented with an obstacle thinks of how to get the casualty past it and implement all of the extra systems that entails, from backup lines to hauling systems.

There are often contradictions – during a search of a vertical system, a personal caver may decide a 5ft pitch is trivially free-climbable, or just needs a short ladder or handline. A rescue brained rigger would see that as a major obstacle for a stretcher, so while he may fit a fast handline to get his search group down, he is also starting to plan more anchors, ordering up another rope and gear kit and so forth. There are many cases underground where an obstacle is trivial to sport cavers and so has never been anchored, so there is a time element in placing them. The rigger may decide in the first few seconds that this 'trivial' obstacle makes the entire route too difficult to use and so plans a search for others. It is not about picking a knot quickly, it is about standing back for a few seconds and making a call on the entire scene.

This mental separation from the scene is a learned skill just like anything else. Some people are also a lot more adept at it than others – some can assimilate the information from an environment and analyse it very quickly, others have to sit and think a while. This may not be a bad thing so long as they come to the right answer when they do, but a rigger also has to be in charge of the system he has built when it is being used – when failures and problems need instant and decisive solutions. Some can handle it, some cannot. It's the same in all emergency roles; there are thinkers, doers and followers.

We have decided on a shopping list for a rigger's training:

- Full knowledge of all aspects of rescue ropework (i.e. all of this book!)
- Ability to absorb a scene and construct a solution efficiently and without help
- Adaptive to problems (lack of gear, uncooperative rock and so on)
- Appreciation of handling a casualty and stretcher
- Team leadership skills

The last bit is important – a rigger cannot usually do all the ropework himself, so he must be very efficient at transferring the mental images in his head to instructions that his group can implement. It is no good shouting at people when they can't see what you are aiming for, and there is no easy way underground to gather around a table with pen and paper.

To get to this point you need to start of course with a competent vertical caver. Moving personally through the systems he is rigging needs to be second nature – to go Zen for a moment I have been known to tell students that a good rigger 'flows' through the ropework, not climbs past it. Just as a police driver cannot be expected to learn pursuit if he has problems driving himself to work in the morning, you have to pick your men. This can create political tensions in a volunteer team, with the Animal Farm arguments bubbling up about people being more equal than others, however in a professional team the idea of specialism and 'rank' is perfectly normal, so passing that onto volunteers is not a bad thing. People complaining that the riggers are getting to much power and kudos can be reminded that there's nothing stopping them trying for the same job.

Given a good vertical caver, then the first thing to do is get their rescue brain installed. It is unlikely that you would select a new recruit for rigging, so we can assume that the trainee has been on many team practices or callouts and so has seen the system in action, but it can surprise trainers how little team members know about what they are being asked to do. Attending practices and callouts for years may not help one jot in learning the rules of redundancy and tension on traverses. There is a big element therefore of sending the trainee off for a little while to read up on the differences with rescue rigging (the basic rules and premises) before throwing them into the details.

Learning and practicing the techniques (hauling systems, anchors and so forth) are best done outside the normal team events, but with other riggers if it helps. Some trainees will prefer a 1-on-1 with a trainer, as they prefer to make mistakes in private. Others will like the group-based approach, but they cannot be allowed to hide within it. One thing is clear though – there is no time on a team practice to teach riggers anything useful. To absorb a new technique or item of equipment most people will need to go over and over the same practice pieces until it sinks in – doing it once with 50 men watching is not going to help someone learn, for a short while they may remember enough to copy it again but long-term they do not learn the how's and why's. I suggest therefore that the training of riggers be planned completely independently of team practices, which can be used as 'examinations' for the riggers' new skills.

> A technique commonly used for efficient professional training is the notion of the 'skill station'. Here a group of trainees alternate individually between set-piece exercises designed to deal with a specific skill (such as rigging a Z-rig or placing bolts). A short timescale and repeated changes help the students to remember what they learn since they do not have time to get bored. Beyond this are events – larger tasks that may need one or more students at a time, and take longer to implement. Examples include rigging a traverse or constructing a set of anchors in an awkward position. It can help greatly in these events to have a small group of 'professional assistants' on hand, who can act under the direction of the rigger and follow their instructions but are told not to offer advice.

Some trainers let their students watch each other, some do not. It is a matter of preference, however if you are not one for voyeurism then a group debriefing session is vital after the practicing, so that different solutions can be debated. Often there is no one correct method, and learning from others helps prevent the student getting locked into their own set of ‘favourite fixes’. Bad habits are difficult to pass on but easy to keep to yourself.

Without a formal hierarchy there can be issues during training where the trainer reprimands someone and they take offence to being told off. As a trainer you must learn to handle your students impeccably – you will sometimes make mistakes yourself, or a student will see a better way of doing something, so accept humility is part of the job just as is authority.

Also your job as a trainer is to be constantly questioning your students on why and what they are doing and thinking. Give them frequent ‘what-if?’s to answer, and vary the parameters of the exercise if you see that your students have got embedded in a solution and are no longer watching the bigger picture. There is a fine line in getting this right – you can easily get a reputation as an impossible taskmaster, but remember that volunteer or not, these people are training to save lives in an extreme environment where they will be planning and installing the systems without help – if you do not feel confident in them, they are not ready. I do not want you to think that I am aiming at a military system of regimented instruction and obeyance, as that cannot operate efficiently without all the other factors of discipline that the military system enforces. However, playing about in a group of friends is equally unable to turn out skilled and efficient cave rescuers.

Simple components

Several simple techniques and scenarios have been shown to be of use in training riggers, including:

- Tabletop exercises
- Rigging using less than adequate equipment (improvisation)
- Rigging in extreme positions (very tight pitches, waterfalls, loose rock, etc)
- Pop-quiz random questions (‘which is stronger, a bowline or a figure 8?’)
- Impossible exercises (where the goal is to see if the student realises it’s impossible)

These are commonly used for industrial and military training as they can help instil the rescue-related aspects of the work independently of the sport caving techniques. Some examples are given later in this chapter.

Testing and validation

In a volunteer team there is usually no formal structure of testing and validation of team members for rigging as there is for ‘external’ skills like first aid. At present there is limited benefit in having external or national ‘qualifications’ for rigging, though industrially this is in place in some cases and being adopted in others. Teams tend to shy away from anything involving a course and an exam, if only for the fact it costs money, but I would suggest that there is no justification NOT to implement some internal system. To a caver with no first aid skills, the work of a paramedic can seem illogical and mind-boggling, and to that paramedic the notion of SRT and reading the safety of a boulder slope by eye can seem equally beyond humanity. A rescue team member wishing to gain medical abilities assumes that it will involve examination and ‘approval’, so why not for a rigger? One of the primary aims of this book was to demonstrate that rescue rigging is not just an extension to sport caving, it is a whole different skill in itself. You need one to do the other, but you also need to learn and remember things you will never want, or need, to apply on a sporting trip.

Strictly on a personal level I would like to see a set of recognised standards for cave rescue rigging training, though I would not wish to see that used to justify charges and fees. The life of the casualty is in the hands of the riggers just as much as it is in the hands of the medics, and if for no other reason than the inevitable call of litigation, teams should know what their members know and be able to prove to some extent why they believe them to be competent. It would be tempting to push in an extra chapter here with syllabi and examination schedules, but that is for the national bodies to debate, this book is here to document techniques, not politics. Teams should however seriously consider an internal method of keeping track of who has been trained in what, and if need be have an ability to control the duties each team member is permitted to use on a callout to reflect their training.

14b. Relationships to industrial qualifications

Rather neatly this brings us on to the external qualifications that riggers can obtain. Almost all of the time this is via their occupation, though some regions have tried using external training when deals have been brokered. The NWMRA, for example, has sent candidates from it's member teams to a commercial rope rescue training centre within their locality which is commonly used by the Fire Service, as a way of crossing over skills. The danger with all industrial qualifications is that they can engender bad habits when applied to the underground world, so in some cases an industrial rope worker can be a liability on a cave rescue unless they can adapt to the territory.

In the UK the national body responsible for the rope access industry is IRATA, which has a multi-level training and certification programme for its members. A combination of accrued time, practical and theoretical examinations by assessors gives a candidate certification for a set period of time, and this is usually a pre-requisite of employment in the UK rope access trade. The IRATA rigging methods are regimented and documented, and reflect the need to comply with HSE regulations, so concentrate strongly on backups and redundancy. There is also a healthy dose of PPE, both of which are of help in rescue work, but are not in any way designed to work with rescue loads. An IRATA technician is trained to perform unaided rescue of a stranded SRT worker but is not trained in the use of hauling and stretcher systems except at the higher specialised levels. IRATA does not deal with confined space rescue.

There is hardly any benefit in a team member going out and getting an industrial qualification (for one, it costs a great deal!), but if they gain one via work then it can help them on the team – however watch that they do not start over-enforcing their workplace regulations.

Personal qualifications (such as CMLA / cave leader, instructor and so on) are not of any significant benefit to cave rescue rigging. They may show an individual is a good vertical caver, but there is usually no rescue element to the training except impromptu self-rescue and assistance.

Some teams will have access to the training facilities used by the emergency services or armed forces (Fire Service training sites are often well-equipped for ropework, with lots of nice towers). Whilst gaining access to use the sites for team/rigger training can be difficult, there is a great benefit in getting team riggers to attend and observe these other agencies in action. On a major incident, cave rescue teams can call on the Fire Service or armed forces to assist (or vice versa) and they have a dramatically different way of doing things. After watching the Fire Service ‘rope rescue unit’ train at a location in the UK a while ago I can say with confidence that the sorts of equipment and techniques they rely on would scare the caplamp off a cave rescue rigger, so a healthy knowledge of the differences is an enormous benefit before expecting a group of ‘outsiders’ to understand what a Z-rig-tensioned Tyrolean will look like.

Finally, it has to be said that callouts are a good form of training in themselves. I stress of course that a callout is not the time to be learning how to rig a pitch, but you can often do things on callouts that you cannot justify doing on practices (the placing of anchors on sensitive sites, etc) and so a debrief and inspection after the rescue is of great benefit to those involved (or those who missed that callout). I have lost track of the number of times in rope training (and also on medical courses) that the infamous sentence

“If this was for-real we would do ---------- but we won’t as it’s a practice... you get the idea…”

is heard. This is all well and good for the trainer, as he probably has done it for-real. Be wary of letting your students off without ever trying it for want of the waste of a rope or a handful of metal. The buzzword in paramedical training now is immersion training – everything is done to make the training seem, look, feel and smell like the real thing. An infamous Welsh doctor teaching rescue teams in the 1980’s was know to have a secret clan of amputees on hand for the ultimate realistic injury… I am not suggesting you go that far (burying yourself so you can get dug out is pushing it a bit), but the idea of simple things to make it real is worth striving for. This is expensive and so for volunteer teams can be difficult, but the closer to reality you can get the better you will be when reality is what you’re in. Typical example is rigging a traverse – you know it’s a lot harder when there are no footholds, so find somewhere to practice where there aren’t any! Don’t haul an empty stretcher, fill it with a bodyweight of sandbags or rope.

14c. Scenarios

Finding ‘interesting’ scenarios and skill stations to train on is the hallmark of a good instructor. This comes often with time, but also with available resources – if you’re based in Kent then training on a 1000ft mineshaft presents some logistical issues. Here I have tried to put down a few suggested scenarios and the ways you can alter them as they progress to stir the little grey cells of the riggers you are teaching. There are benefits in just taking the gear out of your team store once every few weeks and ‘playing’ with it – in the UK the majority of rescue teams do not get enough callouts to keep their members as familiar with their own kit as the statutory emergency services are, and it can be surprising how quickly the exact method of lacing up a stretcher or bolting together your winch frame can be forgotten!

If you're in the mood to try out some evil (or fun, depending on your viewpoint) scenarios with your riggers, maybe some of the below will get you going:

1. Hauling and lowering on a tight vertical pitch
    a. Insist on a few changes in direction without warning
    b. Try restricting the gear available (especially for the hauling system)
    c. Try a counterbalance haul instead of a top-based haul
2. Hauling and lowering on a slanted pitch
    a. Using deviations and guidelines to send the stretcher down clear of the rock
    b. Simulate a jam or the failure of a belay
3. Tyrolean traverses
    a. Using a highly-sloping runway
    b. Using limited anchors at one or both ends
    c. Crane-jib traverses for picking and placing a load at marked points on the floor of a gorge (add a time element if you wish to make it nasty)
4. Knotty traverse (an evil notion)
    a. Transport of a heavy stretcher keeping it exactly horizontal
    b. A combination pitch (a traverse leading out to a vertical lower with no footholds, truly a hideous job for any rigger)
5. Limited anchors
    a. Using props and non-standard devices to secure loads
    b. Working with anchors a long way apart (more difficult than it sounds)
    c. Bolt-placement for hauling systems
6. Water
    a. Hauling systems on wet pitches
    b. Tyroleans and traverses over open water

There is also a method of practicing and training called 'lights out'. This is common in the military and used to be used a lot in maritime ropework, simply out you learn to recognise and do your job in the dark. It is difficult to apply this to every aspect of cave rescue rigging, but in theory it is possible to do. SRT relies on contact with the rope, and without light you should be able to operate by feel. Clearly you cannot place anchors and rig pitches in the dark, but you can practice making and using hauling rigs, tying and untying knots and using the commercial equipment in your kitbags. A competent rigger should be able to take a bag of rope and gear and make up any hauling or belaying system with his eyes closed, it is an interesting and challenging way to see how good you really are! I do not have to say that lights out training is not done in a cave with no caplamp – you cannot train someone not to walk off a pitch! Playing in a dark room or with a blindfold on is just as useful, and the blindfold method helps as the instructor can watch!

14d. Training and insurance

This is a little section but important. When on a callout, members of a cave rescue team are insured both personally and against liability, either by the team or by the statutory agency that calls them out. On training and practice events however the insurance may not apply in the same sense. This can raise three issues that teams need to look into before adopting the idea of independent training sessions for riggers:

1. Is the team equipment insured against loss or theft if not on a full team callout?
2. Are the team members covered for third-party liability against landowners?
3. Is access to training sites conditional on item 2?

Most team members will be active cavers and have personal liability cover, either through a club or directly. However, it could be argued that a team training session is not covered by 'sport', specifically if using rescue-specific methods. Also, agreements to use private sites such as quarries and commercial buildings that some teams have in place may be based on the idea that the team provides insurance, which may only apply on 'official' team practices. This is often true when the team's insurance is provided by the Police, who will only sanction it for pre-arranged official events, often limiting the number of these events in a single year.

The most important aspect of training is confidence in your own abilities. You cannot train for every situation, nor can you supply all the equipment to handle every obstacle. A rigger's role is to pass the obstacle using the resources he has, in his hands and in his head. He must trust both.

15. The future of rescue ropework

This chapter has been interesting to plan. A few years ago I would have said that the general future of cave rescue was to carry on as it is now, having a bit more paperwork and legal stuff to handle but generally hiding from the public as cavers tend to do. With the changes in the world in the last few years, potential roles for cave rescue teams have emerged that were not thought of beforehand. The events of 9-11 have shown that it can be all too possible for a major confined-space rescue to be needed at any place, at any time.

Cave rescue teams have a wealth of expertise in working in extreme environments that is unparalleled in the emergency services. Their combination of high-angle rope rescue, confined space working, rock drilling and digging, searching and recovery, even diving and explosives, mean that they are in a prime position to develop closer links to ‘surface’ rescue structures in the future. That is not to say that the primary and most common role is not to help those in danger underground, and that the volunteer caver system of recruitment should change. Cave rescue teams will always exist to help cavers; that is fundamental. However the encroaching needs to meet legal standards of record-keeping, training and operational readiness mean that the team is increasingly worth more than just as a service to a niche sport. Whether teams start to adopt these other roles depends on politics, and the willingness of the members. Personally I can see an increased use of cave rescue teams to assist, and even respond primarily, to surface rope rescue and confined space incidents. This would involve closer cooperation between the teams and the statutory bodies (Fire Service, Coastguard and so on), as well as changes to the training and approval of teams. The mountain rescue community is evolving *now* to meet these new challenges, with increasing regulation of training and widening of roles; historically cave rescue follows the MRC in things like this, so it is to be expected eventually.

The one thing that we know will change in UK voluntary rescue work is the impact of EU regulations. At present ‘rescue’ falls neatly between the bars of the PPE framework and the CE/EN standards, and this will have to change. More than likely will be an imposed requirement to comply completely with PPE ‘work’ regulations for any team serving to rescue members of the public, irrespective of their status. EN standards specifically for rescue equipment are in the pipeline, as are subtle changes to the existing raft of standards to account for higher loads. New CE/EN standards are not retrospective, so it will not affect the equipment you own already – but it may influence your choices in the future. Issues like team member training are likely to be influenced by legislation in the same way that medical training is being influenced now. During 2003/2004 all team members dealing with a casualty will be required to hold a valid and approved first aid qualification, the same could easily be argued for the technical aspects of rigging and ropework. This is not the same as requiring all team members to hold a local cave leader or CI badge, that is simply proof of personal ability in the sport. Rescue ropework is a skill in itself, and as such I believe deserves recognition.

Within the UK cave rescue has always been a volunteer-run and volunteer-staffed service offered for free to those needing assistance underground. Whilst the encroaching legal requirements mean that teams have to increasingly operate on a professional basis in terms of skills and paperwork, I firmly believe that to remove the volunteer basis would damage the service irrevocably. Hopefully by not charging anyone for LOAL I am making a hint to all the other generators of paperwork, rules and regulations that the one thing teams do not need is a bill.

16. References

A large amount of the non-numeric data in this book (techniques, procedures and designs for rigging) are based on the author's experience and the common practices of UK cave and industrial rescue teams and riggers. Data on the performance and use of commercial devices is obtained in all cases from the manufacturer, either by reference to the supplied instruction manuals or by direct contact with the product engineers.

Specific numerical data has been quoted based on published sets of research or from direct information supplied by manufacturers and/or third-party tests. Whilst the author cannot be responsible for error or omission in this external data, it is safe to assume that data from reliable sources is equally reliable, and so we have only used sources from official research or standing rescue teams. Data collected by individuals and published non-professionally (such as via a personal or club website or magazine) is not used in this book.

16a. General ropework books

Whilst not all specifically aimed at underground rescue, these books may be of interest. A lot of the data on knot strength has been derived from these books (averaging out where there is disagreement). All of the books are written and aimed at the US market.

- *Rope rescue for firefighting* by Ken Brannan (ISBN 0912212616)
- *Engineering practical rope rescue systems* by Mike Brown (ISBN 0766801977)
- *Technical rescue riggers guide* by Rick Lipke (ISBN 0966577701)
- *Confined space and structural rope rescue* by Mike Roop (ISBN 0815173830)
- *High angle rescue techniques* by Tom Vines (known as HART) (ISBN 0815159001)
- *On Rope* by Bruce Smith et.al. (ISBN 1879961059)
- *The essential technical rescue field operations guide* by Tom Pendley (ISBN 0967523826)
- *CMC rope rescue manual* ed. by James Frank (ISBN 0961833777)

16b. Equipment test reports

Published data on the performance of ropes and equipment has been taken from many sources, usually via the manufacturer to confirm the reliability of the data. Some specific sources include:

- Eco-anchor test results from Les Sykes of the CNCC (published via their newsletter)
- Info on the Petzl I`D was sourced via Lyon Equipment (www.lyon.co.uk)

- Some data on the high-load performance of belay devices came from Technical Rescue magazine (www.technicalrescuemagazine.com)
- www.dsm.com/hpf/support/rcn/fiberprp/~en/mainfric.htm has data on friction calculations and results for Dyneema
- www.techrescue.org/vertical/vertical-ref4.html has calculations and suggestions on the loads on Tyrolean traverses (aerial ropeways)
- www.tensiontech.com/papers/fiber_id/index.htm has data on the identification of fibres within ropes and webbing
- www.dsm.com/hpf/support/rcn/fiberprp/~en/creep01.htm discusses the plastic deformation and creep of Dyneema
- www.wireworld.com/fiberline/yarntabl.html has data on the performance of several synthetic yarns used in ropemaking

All other data relating to the performance of commercial equipment is sourced from the manufacturer.

16c. Standards and Government sources

The official text of BS/EN standards is available to purchase from the HMSO catalogue at www.the-stationery-office.co.uk . Some extracts are published on the Web, the full text is not.

The PPE Regulations website at
europa.eu.int/comm/enterprise/newapproach/standardization/harmstds/reflist/ppe.html
has FAQs and extracts from the current Regulations, plus a downloadable link to the proposed new version of the Regulations, not yet in force.

16d. Other sources of information

Within the UK any official guidance for cave rescue teams should be obtained through the BCRC and the team insurers. Many teams are also affiliated to the local Mountain rescue Association in their area, and the MRC has an open-access newsgroup server at news.mountain.rescue.org.uk, which can be a useful place to ask for opinions and comments.

16e. Terms used in this book

The majority of rope rescue texts are from the USA. Terms used for climbing equipment, knots, rigging procedures and for caving often differ across the Pond, so we have stuck as rigidly as possible to a set of terms and definitions as given below. This book is squarely aimed at rescue-team cavers of some experience so unambiguous terms (karabiner, etc.) are used without explanation. The lists below cover terms that (certainly beyond the UK) cavers may use for entirely different purposes, and so if you are reading this book from a house in the USA you may need this section as a translation tool!

I have borrowed terms from both caving and climbing throughout this book, hopefully clear to all readers and in agreement with 'Climbing terms and techniques' (Crocket, 1990).

Ropes etc.

LINE refers to a length of rope rigged to perform a specific function (e.g. as an SRT line on a pitch or as part of a hauling system), as opposed to something lying about with no intended use.
ROPE is the generic term for load-bearing ropes, including one still in a bag.
CORD is any rope less than 9mm in diameter and deemed not fully load-bearing (e.g. as used for prusik loops, footloops etc).
BUNGEE is a kernmantel construction cord with elastic (rubber) cores used for tensioning in non load-bearing situations (e.g. to keep a chest jammer in position)
WEBBING is woven load-bearing material either in a flat profile or produced in an endless tube, as used to create belay slings, quickdraws or belts.
TAPE in this book refers only to adhesive tape and not to webbing.
WIRE refers to metal rope of a laid construction, used for slings, tethers and to produce items such as electron ladders.

When put to a specific use lines have the following standard names:

SRT LINE is a static rope fixed in position and intended for the use of one or more cavers to climb or descend using personal single rope techniques.
BELAY LINE is a static (or dynamic) rope that provides a safety backup in the event of primary system failure but which in normal use experiences no loading. It also refers to a dynamic rope used to protect a lead climber (as is usual in rock climbing).
HAULING LINE is a static rope used to support a casualty, items of equipment or other dead-weights during controlled raising and lowering, and which is in tension in normal use.
SAFETY LINE is a dynamic or static rope routed around a hazard and acts as a point for cavers to attach to. It is a fall-arrest device and is not loaded under normal use. An example would be a loop of rope connecting together a group of cavers working near the top of a pitch. Do not confuse a SAFETY line with a BELAY line. SAFETY lines exist around specific hazards, BELAY lines are used to protect objects being moved by hauling systems, or lead climbers.
SPAN LINE is a static rope or wire spanning between anchors in a traverse
TOW LINE is a static rope or cord fixed to the travelling pulley(s) on a traverse and used to pull them along the span lines.

Normal UK caving terms are used for line and rope rigging that forms part of the normal sport caving repertoire (such as ‘deviation’, ‘traverse line’, ‘rebelay’ etc).

Mechanical devices

AUTOBLOCS are knots that are designed to wrap around a fixed rope and grip it, usually in one direction only. The prusik, bachmann and penberthy knots are autoblocs.
ASCENDERS refer to any device used to climb a rope by mechanical gripping or friction, and is a group term including rope clamps, autoblocs and other devices.

ROPE CLAMPS are mechanical rope-climbing tools involving a toothed cam gripping against the rope, such as the well-known Basic, Croll and Expedition devices by Petzl, the Kong, Jumar and Rescuecender and many others. Also referred to as 'jammers'. All ascenders are not rope clamps – the terms specifically refers to a device with a cam action.

DESCENDERS refer to any controlled-friction device specifically designed to allow descent of a fixed line. The term includes basic devices such as the figure 8, plus PACDs such as the Stop.

PACD (Positive Action Camming Descenders) are mechanical devices which generate friction by the passage of rope around two or more fixed cams, parts of which are designed to move together under the action (or inaction) of the user and which grip the rope to prevent further descent. The Petzl Stop, I`D and SRT descenders are the most common examples of PACDs.

BECKET is a little-known term for the fixed attachment ring built into many pulleys opposite the main attachment point and intended to tie off the rope when building compound pulley systems.

Other devices and terms.

PITCH is any vertical drop in a cave (a shaft, winze or opening into a cavern) which requires ropes or ladders to negotiate. The 'flat' ground at the top of a pitch is called the '**PITCH HEAD**'. Standard terms for other natural features of caves are used.

BELAY is the process (or devices intended for…) the protection of a moving climber or object using a controlled point of friction. The important point is that a belay system is not under load until something goes wrong. If the rope is under tension at all times it ceases to be a belay and instead becomes a hauling line.

KARABINER is a metal ring with a spring-loaded gate as usual. Rather than fight over the choice of spelling (KAR… or CAR…) I have chosen the version suggested by the Oxford English Dictionary.

BOLT is a metal device sunk into rock to provide an attachment point and can be secured by resin or expansion. Strictly speaking in the UK a 'bolt' refers to the device set into the rock and the metal attachment ring is a '**HANGER**', though there is little point in having one without the other. I will use the term 'bolt' to refer to any point of attachment that is fixed into a hole in rock by whatever means, as 'hanger' can cause some confusion when talking about hauling rigs and loading.

ANCHOR is the generic term for any fixed point of attachment (for a rope or other object). It includes bolts, natural rock features of suitable strength and design, trees, car axles, small buildings and piles of exhausted cavers. Care should be taken to note that the term 'belay' as used in the USA to refer to an anchor is used in this book to refer to something completely different.

TETHER is a flexible strap (usually with eyes on both ends), produced from webbing, wire, chain or rope and designed to wrap around a large diameter anchor to provide a suitable point of attachment.

SLINGS are endless sewn or tied loops (usually of webbing or rope) designed for similar purposes as tethers.

QUICKDRAWS are short slings (usually 20cm circumference) and used in the climbing world to join two karabiners together into a flexible 'runner'. In this book quickdraws are used for several parts of hauling systems where a small extra length is needed between objects.

SRT (single rope technique) is the group of methods used by a caver to ascend or descend a single fixed ropes by means of mechanical devices fixed to his person. If the control of the movement is from somewhere else, that caver is no longer conducting SRT, instead he is the load in a hauling system.

ELECTRON LADDER is (for our international readers) a metal flexible ladder produced from thin steel wire (usually 4mm diameter max) and designed to support one body mass in ascent or descent. It is usually fitted at the top with a **SPREADER** (a short y-shaped wire tether) that brings the two wires together at a single attachment point.

ACROW is a cannibalised trade name for a steel prop with an adjustable length, usually achieved by a threaded collar and pin system. Used for supporting a weak roof or to fix across a passage to provide a rapid anchor point.

MAILLONS (maillon rapides) are metal oval, D-shaped or triangular rings with a screwed sleeve covering an opening. Called 'quicklinks' or 'screwlinks' in the USA and beyond.

The chapter on knots and rope uses many terms for the parts of a knot, the components of ropes, etc. which are detailed where first used

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A final note to those of you who have got this far…

Creating this book has taken a lot longer than expected, partly from other constraints on my time but mostly from the rarity of data in the public domain. I would like to think that the questions raised throughout this book will lead to more rescue-rated test data becoming available, and one day letting this book quote numbers that everyone agrees on! Finally I would like to say that if anyone feels like writing another version of LOAL, then I for one would be eager to read it… and good luck to you!

Dave M *[somewhere between his PC and a large bottle of Black Sheep...]* ***March 2003***

This is the end of part three of the three-part edition

This part was last modified on 06 Mar 2003

Changes in this issue: Inserted pic and text into 10b, some tinkering with indexes and page breaks.