Contents

The original edition of Life On A Line was several years in the making, and was expected to circulate around a few cave rescue teams and sport cavers. In reality, we've seen a little over 100,000 downloads of the book, and almost half of those are outside the 'planned area' of the UK. Copies have surfaced as part of conferences, been adapted into official training programs, and been nailed to notice boards from the far reaches of the Urals to Federal agencies in the US and Australasia. Fine by us, but clearly a book written for British cavers needs a lot of interpretation to be applied to urban search and rescue teams, high angle riggers and a TV crew working in the Amazonian rainforest.

The world also moves on, and whilst we have been updating LOAL1 in chunks, it came time to rebuild the beast from the ground down (pun intended), taking into account new equipment, test results and techniques. The book is still aimed at **cave/mine rescue teams working within the volunteer sector**, but it's broadened to fit better with 'paid industry people' such as confined space rescue units and USAR. We've increased the detail on standards and the differences between 'work' and 'rescue', so that teams can decide how to implement the techniques based on their country and legal status, but what we really must stress above all else is that LOAL2 remains a book about rescue. The idea that it's an *emergency* and you, the Insanely Sexy Rescuer, are the last and only hope of the poor casualty is paramount.

A lot of the techniques we describe are possibly not the best to use in day-to-day work or sport caving, where you have all the time you need. LOAL2 assumes someone, possibly even you, has a stopwatch running. We also assume that the team are *space-limited* and *equipment-light*, as with almost all cave rescue it's not a problem to fit 30 bags of pulleys in the team 4x4, it's a problem to afford them in the first place and to get them into a flooded cave at 4am on a cold Sunday. Industrial rescue teams have the advantage of being 'outside' more often, and having the money to buy shiny titanium ladders. Cavers **make** ladders from things they found in a dumpster. So with all due respect to those readers being paid a salary to go rescue people, in this book we won't be solving every problem by collecting a $5000 battery-powered winch from the back of a truck.

When LOAL1 was created it was concerned only with UK practice, so it mentioned CE marking, EN standards and the items of equipment that UK teams generally used. In the Second Edition we have decided, after a lot of debate, to become "mid-Atlantic". This isn't to say teams in other continents are ignored, but looking at cave rescue across the world it's pretty clear that where teams have adopted 'equipment standards' it's based on either the European (EN), UIAA or the American ASTM/NFPA systems. The local copies may have different names, but if we talk about these three then we should cover your rules no matter where you live. In reality we can make it even simpler, as the UIAA standards are now 99% identical to the EN standards - so apart from a cross-reference table in the last chapter we can pretty much forget about the UIAA entirely.

What Life On A Line is *not* going to do is become an *American Rigging Book*. There are shelves of rope rescue and rigging manuals out there, some extremely well-used outside the USA, but based on the surface/mountain/industry rescue systems taught in the USA. **They do not work in caves**. Some very well-respected training schools claim they do, but they don't - *not in the caves and mines the rest of the world have to rescue people from*. The American system of 'soft technology' knot-based devices (release hitches, prusik loops, Italian hitches) and a scant regard for backups is something we have always fought against, and it's not going to change anytime soon. Muddy ropes, constricted locations where you can't get close enough to a prusik to keep a hand on it, and the fact almost every 'industrial' code of practice outside the USA forbids safety systems made of knots when an officially-tested metal device is available, makes it not only impractical and dangerous to apply the out-of-the-box American system to cave rescue, it usually makes it legally impossible. So we are going to include **some** aspects of American caving into this book (like the use of racks) and we're going to include some very selected examples of soft technology where we consider they are actually useful (prusik knots but used selectively, not like the rope rescue equivalent of Viagra). We're not going to turn LOAL into an industrial confined space book - if you're rescuing people from grain silos in the Mid West and your uniforms have pips on the shoulders, then buy another book. If you're struggling to extract a lethargic cow from a clay-smeared vadose rift in the biggest flash flood since Noah bought his umbrella, and your uniform is a plastic suit and army-surplus thermals, you'd be wanting to stick with us.

LOAL2 is also more streamlined. We're not shy of math and technical tables, as you do actually need them - not every day, but you will eventually, one day, need to know what a square root is. We've tried to keep the chapters a little more organised, and so despite there being a lot more in the Second Edition than was in the original, it's not actually any bigger. Some things have been edited away completely as techniques adapt and improve, and we've replaced them with all-new sections on stretchers, casualty care and equipment selection. The layout is sexier, and you've got features that the improvements in PDF have allowed (like a working index and better image quality) but we still accept that some of you will want to print the book out on a home inkjet. For that reason we've not gone for too many cosmetic photographs or strange paper sizes. The book will print out on A4/Letter and although it's intended to be double-sided, it'll work any way you want.

Dr Dave Merchant has again written everything you're reading in the Second Edition*, however the time involved and commitments elsewhere meant he needed to delegate some of the housekeeping so the lifeonaline.com website, eBook and paperback ordering and distribution systems, plus some of the test data and artwork, come courtesy of the 'Author Group' - a constantly-arguing and evolving band of gnomes who forgot to run away when Dave asked for volunteers. It's why the narrative is now in the plural even though there's only one person talking.*

We're grateful to those manufacturers who provided equipment and access to test machines despite knowing we had no intention of endorsing their products or mentioning their generosity. We know that many people have been patiently waiting for LOAL2 for a lot longer than we originally intended - and for that we apologise. Personal and professional issues always arise when you've the least free time, and we roughly estimate LOAL2 has taken 5000 man hours to create. It was planned to be out in early 2006 and finally made it to preflight at the end of the year - but some rather sexy bits of kit have been invented during the delay that we've been able to include only because of it, so it isn't a total disaster!

Finally, before we kick off the book, we'd like to thank those who have supported the first edition by making use of the book, commenting on it and finding the mistakes. The Second Edition of course has no mistakess, so if you find any, you know what to do…

Dr Dave Merchant & the Author Group, Jan 2007

Introduction

1a: The reasons behind this book

Cave rescue is a unique situation, and one which many seasoned 'technical rescue' riggers would avoid like the plague. Unlike mountain, industrial confined space rescue or even USAR, the team has a few demands they must work with on every callout:-

- The casualty can easily get to a place from where rescue is impossible.
- The route and rigging is decided by the cave, and the cave is not helpful. Ever.
- The search for the casualty cannot be simplified – to see around a corner you must go around the corner. Flying overhead with infra-red is not an option.
- The team is the absolutely positively *only* hope the casualty has.
- Exit is usually by the same route as entry. All good cavers injure themselves trying difficult routes.
- Gravity is against you. Water is against you. Your own personal God is against you.

This book is not an advertisement for how amazingly good cave rescuers are, or have to be. The challenges of cave rescue simply mean that whatever techniques are used must be as simple, flexible, robust and reliable as possible. LOAL2 assumes that the team members are all efficient and experienced cavers who can progress through a cave using rope techniques without needing their hands held. They should all be able to follow all of the procedures in the book, because they are all just extensions of the normal 'sport' techniques they use every week. The book is therefore more of a discussion and recipe book than a training course.

LOAL1 made a point around here to say "this is not a training manual". It didn't help, and it turned into one for teams across the world, so this time we'll try a slightly different disclaimer:-

This book may be used to supplement cave rescue training and as an information reference but the authors accept no liability for the techniques when applied in a specific situation. Teams must always plan training and rescues on an individual basis, and whilst this book contains techniques and data of direct use for that planning, it cannot be a substitute for experience and practical training. Use of any procedure or technique described herein is entirely at your own risk. The publishers and authors 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. No part of this book may be used for commercial training. Rescue is inherently dangerous and you are entirely responsible for satisfying legislation, equipment specifications and insurance. No matter how stupid you are, we will not rescue you.

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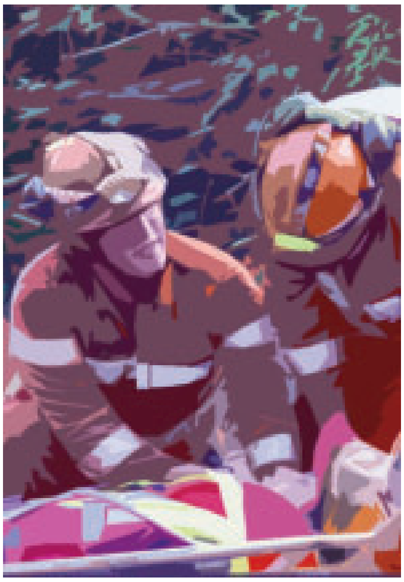
Casualty Care

Ideally, when rescuing someone trapped underground and injured, a doctor trained in PHTLS/ATLS and with advanced cardiovascular management skills should be on scene within 30 minutes of injury. The medical staff will be proficient cavers and fully skilled in the techniques needed for self-propulsion and safety at the site.

When possible, a 750mm dry-core diamond drill should be available for air transport, enabling access to the casualty via a vertical shaft of sufficient diameter for a horizontal stretcher lift to surface. This, and suitable medical supplies to allow for an amputation of the left leg, should be available within 40 minutes of injury and fit on the back of a Jeep.

Only one of those ideas was a joke.

2a: The premises of Casualty Care



In any other area of modern accident response, from road traffic entrapment to disaster recovery, providing adequate medical intervention on site as soon as possible is the goal. Paramedics and fast-response physicians are the norm, and if you were pinned by your legs in an '87 Chevy, you'd expect drugs and people with lots of badges. Not, hopefully, a posse of trolls who once went on a first aid course but slept through the first afternoon. Underground, in caves and mines, we would dearly love to supply trauma specialists to every casualty, clearing spines, stabilising electrolytes and drugging seven bells out of them before anyone even thought about movement. Some teams are lucky, but most find that doctors, as a career fundamental, think going caving is up there with naked tiger wrestling. The rescue team **must** be formed from expert cavers, as anyone else is a liability. Babysitting a doctor through 100ft of passage will take more time and resources than dragging the casualty direct to a ward.

Now this is no insult to medics – if they want to become cavers, then fine. Just don't expect to talk them into it. Similarly, don't expect that a rescue team can handle a casualty as well as the medics can. It's all about directing skills, and some of the best systems (without Superwoman Caving Anaesthetist) rely on training team members to act as remote operators for a surface-based doctor. It takes a great deal of commitment from the team, as they will have to put in *many* hours of training and practice, but the skills needed underground are surprisingly limited. Trauma, airway, fluids, analgesia, heat. Little advantage in doing an OBGYN rotation.

2b: Bending rules, and patients

We're not going to wade off into a book on pre-hospital trauma care training for volunteer rescue teams – that's a different book entirely, and one day we may even finish it. No, here we're just going to cover what a team 'medic' will probably need, and dally a little into suspension trauma, as what we're interested in is how the medical condition of a casualty will affect what we do with the ropes'n'shizzle. The riggers don't care if the patient has recurrent PVCs or gangrene in their left foot, they care if the patient has to be kept flat or upright, if a medic has to follow them at all times, and how long they've got to live.

The last factor is critical, as the casualty usually buys the beer.

Rope & Cord

In a book on cave rescue a chapter entitled ‘Rope’ may seem a little obvious, but this is probably one of the most contentious parts of what we’re saying as the choices of rope, knots and devices applied to it varies from country to country. There is of course an advantage in knowing a fair amount of the properties and abilities of the rope itself, but it tends to be written off as a misplaced appendix, full of chemistry and physics and not worth reading unless there’s 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.

For LOAL2, we’ve tried to update this chapter with new information, test data and product developments – but it’s not as easy as you might think. 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. The problem is, of course, that manufacturers have no commercial reason to spend money on testing old rope, so it’s left to the users to do it. Many groups are trying (the NCA in the UK has a long-established drop-test program) but their data is often unreliable and impossible to compare - drop tests are notoriously difficult to compare if you’re using different knots, weights or edge diameters. There are plans to start a more formalised program of testing in the UK, with donated time on calibrated tensile testing equipment, but this is taking a lot longer to arrange than expected.

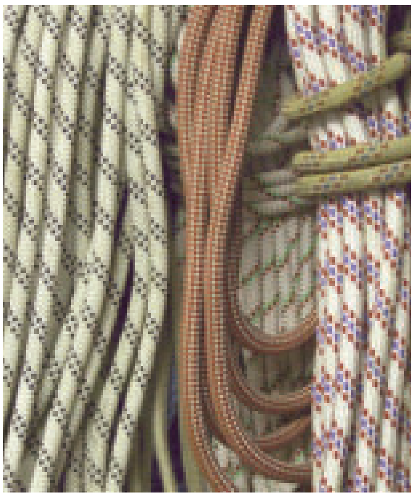
Diameter (mm)	Diameter (inches)
8.5	11/32
9.5	3/8
10	25/64
10.5	13/32
11	7/16
12*	15/32
12.5*	1/2
16*	5/8

One major concession for those readers based in the USA is the issue of inches (allegedly British cavers say inches are not important... Americans know width is everything). Rope elsewhere in the world is described in metric units (millimetre diameter, kilonewton force, etc), but in the USA the great majority of teams and training centres use imperial units – inches for diameter and pounds for force. One problem of course is that the exact conversion never really works, but for this book we will use the table on the left.

** It’s rare in the EU to see ropes larger than 11mm on general sale.*

As far as this book is concerned, “rope” is a full-sized length of rope used for the main rigging. “Accessory cord” is made the same way, but is thinner. Accessory cord is used for things like prusik knots, and to tie spanners to your butt. It will never be used to suspend a human or to form an anchor sling. The word “line” refers to a rope that’s rigged to do a job - so a rope on the floor can be a “belay rope” if that’s what the bag says, but a rope belaying someone is “the belay line”. This is slightly different to the way some emergency services talk about ropes and line, but we don’t care. They can call it what they want, we’ll call it what we want.

3a: Construction and materials



The best and simplest way to understand the construction of a rope is to take one apart. We strongly recommend that all team riggers learning the trade start by taking a knife to some old samples of rope and learn by dissection.

All modern ropes used for rescue underground are of two-layer kernmantel construction (with one exception as we’ll describe in a moment!), 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 should never happen. EVER. They are unpredictable, incompatible and should be burnt on sight. Luckily, they do burn extremely well.

The anatomy of a rope

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'. Americans spell it 'kernmantle', but as the word is German you can't actually screw around with the spelling and claim it's OK. Mantel. End of argument, talk to the hand.

The sheath of all kernmantel rope is a plaited construction, again designed to impart no nett 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.

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 nett torque on the rope as there is for a laid construction, so the rope won't spin around as it stretches. This is further improved in many ropes by including equal numbers of left- and right-handed twists (called S and Z twists). 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, even with a knife, to tell what type of rope they've 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 large differences in behaviour. Obviously the most extreme result is that a dynamic rope, and the person on it, taking a fall of FF2.0 should easily survive without massive damage. Semi-static rope will probably not.

Modern SRT devices (ascenders, descenders, belay devices and so on) are specifically designed for use on kernmantel rope manufactured for climbing purposes (EN and UIAA/NFPA rated 'industrial' ropes, plus sport climbing and caving ropes). Using such devices (for example an autolock descender) on any other type of 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 that may have collections of 'other' rope in their truck.

Details on the materials used in rope and webbing are in Chapter 8

Introduction to knots

Naturally a book on ropework cannot avoid knots, though surprisingly few are needed for the general day-to-day rescue rigging we 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[4] has just shy of four thousand distinct forms of knot, hitch and bend, but with all due respect to Clarence it was written in 1944 and aimed at sailors on sailing boats. Some of the knots we're using literally weren't invented when Ashley was writing, so by all means borrow a copy and read it for fun, but there's no point in actually buying one unless you own a ketch.

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 book is therefore to select the minimum number of knots and provide the maximum amount of information on each. We cannot emphasise enough that every rigger in a team should be able to recognise, tie and untie every knot in the next 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 Service, may have several different 'acceptable knots' to our 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 structural 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, email digests, websites and fights in bars 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. Countless tests have proved that knots like the Figure-8, Figure-9 and Bowline 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 - it just proves that a knot is a dynamic object with 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. For LOAL2 we have personally retested all our knots on calibrated tensile test machines, using a wide range of ropes, and the 'percent strength' figures are still just a ballpark average. A Figure-9 is 'stronger' than a Bowline on most days, in most ropes - but you should never put so much tension on a rope that you actually care!

Item 3 is important but should not always 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, professional teams usually follow a protocol where another rigger checks the system 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.

4a: 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.. Sailors get around a bit. There are many other terms for ropes and knotwork, from the familiar 'bitter end' (the end of a rope tied to an anchor, from the original term for a dockside bollard) to the obscure practice of 'choking the luff' (which is still illegal in 12 States). Whilst useful in quiz matches they don't help in learning and we shall stick to the basics.

First question - what's a knot?

Well, a **knot** is an interlaced series of turns and loops in rope, cord, webbing or something else long and pliable, without structurally breaking apart the rope, webbing or wire to do it. Everything in this chapter and the next will be a knot. Knots don't have to attach the rope to anything, don't have to form a loop or even serve a practical purpose.

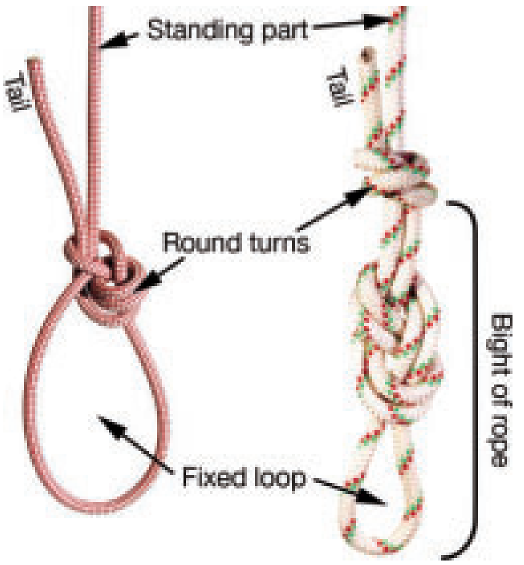
A **splice** is a method of joining rope by structurally breaking it into components (strands) and knitting or weaving them together. Splices can join ropes end-to-end or form eyes, but are only really valid for 'laid' rope. Splicing kernmantel is possible in theory but never done in practice.

A **hitch** is a knot that attaches the end of a rope to an object (anchor, pole, etc.) or attaches one rope to the middle of another (a Prusik Knot is a hitch). If the object is removed the hitch falls apart - so the loop formed by an Alpine Butterfly Knot isn't a hitch even if you ram a stick through it. A Constrictor Knot is a hitch.

A **bend** is a knot that joins two or more ropes together *at their ends* and without the use of an anchor.

OK, so now we've got you confused as to if the thing on your shoe is a knot, a bend or a hitch (it's a bend by the way), we'll introduce some terms that we'll be using in the next chapter:-

- 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 used. In many knots the tail *can* be load-bearing (such as in the Figure-8 loop on the right) but in many it cannot (such as in the Bowline on the left). Without a reasonable length on the tail, some knots that slip under tension can be dangerous - most knots should have a tail of no less than 20cm.
- A bight is a doubled-up section of rope. Knots tied 'on the bight' are tied using a doubled-up section of the rope *as if it were one length*, 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 Figure8- Loop Knot to the right is tied on a bight of rope.



Essential Knots

As we've just discussed, 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 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. For sport caving and industrial rope access, many people get away with only three or four knots, and cope just fine. In rescue rigging, there are issues, as we've already droned on about, that don't figure in normal life - so we need some more knots.

All of our knots assume you're using a rope, or two ropes of equal diameter, with the exception of the autobloc and water knots. Where a knot can be tied in webbing we have said so, and where it has problems we've said so too.

Names

There are eighteen main 'names' of knot in this chapter, though there are several types in each - the Figure-8 has five different variations but all follow the same basic pattern. We know of many candidates for knot nineteen, but so far every time we've found an existing knot in our arsenal that does the job. Learning and remembering all these knots is hard work, and we're trying to keep this as simple as possible.

Each knot has a code, so that when we're talking knots for our rigging chapters we've got a labelling system. The name of a knot is always in capital letters, as sometimes we want to use the same words to talk about something else. For example a Figure-8 is not the button on your phone below the figure 5. A Prusik Knot is a particular style of autobloc, but a 'prusik loop' is just a piece of cord. You may be using it to tie a Klemheist, but you'll still call it a prusik loop. Some of the names we've chosen may be different to those you use yourself - the most famous is the Barrel Knot (double fisherman.. triple fisherman.. cowstail knot.. retainer knot.. etc). We've chosen names based on our own voting system (arguments involving emails and beer were conducted; last man standing names the knot).

Strength figures

Each knot has a value for 'strength', based on both our own tensile load testing (the author group found a test machine lying about and the rest is history...) and published test results from other reputable groups. Our results showed very little difference across diameters and rope ages but quite a lot of difference between materials - the slippery modern cords in Spectra or Vectran tended on the whole to be weaker by between 10% and 30%. We're continuing the research with different polymers and weave patterns - anything interesting we find will be posted to our website. Above all it's important to remember that the strength of a knot is unpredictable. The most tested knot is the Figure-8 Loop, as it's part of the EN1891 product test - and yet looking at the data from the top ten manufacturers the strength varies from 59% to 88%. Most knots give a results within about a 10% window but the more complex the knot, the wider the range - so a Tape Knot is more predictable than a Figure-9 Loop. For the knots in this chapter, tied in low-stretch kernmantel rope in nylon or polyester, the strength measured in a slow tensile pull is pretty much the same as the strength from a dynamic drop test. More complex knots with internal movement may not behave the same way, and one of the critera we've used to select our 18 essentials is reliability of performance.

Our advice is simple - you can't ever be sure how strong your knots are, but if you assume they're all only 50% then your rigging will be safe.

For clarity on the page, some of the photographs show shorter tails than would normally be suggested

1. Figure-8

F8

Breaking strength: 65 - 75 %
Reasonable to release after loading
Performance not affected by water or mud

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.

A simple Figure-8 at the end of a rope as a stopper knot (see right) 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 a Figure-8 loop knot in the bottom of ropes, as clipping on a new rope is quicker and safer than hanging there rethreading a knot. Any stopper knot is more than likely to snag when hauling ropes back up a narrow rift, so the last person up may want to untie the stopper and tidy up the last few metres once safely above it.

Figure-8 loop knot

F8L

This is probably the most common knot in all of caving, climbing and rescue - forming a loop in the end of a rope is something you do every few time you rig a pitch, and the time-honoured Figure-8 loop is the one people use and abuse the world over. Always make sure the tail end is at least 30cm long - if it's excessively long you can tie the tail around the main line with a half-fisherman like in the photo. **The tail rarely slips, so this extra knot is not there to prevent some catastrophic disassembly, it's just to prevent anyone abseiling on it.** Dressing a Figure-8 should mean that it looks symmetrical and flat, like the photo above. Having the two ropes twisted inside the knot will make the entire thing lock solid under load and can give you a nightmare of a thing to untie!

For rescue loads, the stronger Figure-9 knots should be used to make loops in the end of a rope

Important note on direction

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 above and follow the standing part into the knot – you can see it turns **outside** 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 inside the tail end. Under load, the standing part makes a 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 with one very tight loop and one protruding section, you can bet that it was tied the wrong way round.

6. 'Alpine' Butterfly Knot

ABK

Breaking strength: 60 - 70 %
Easy to release after loading
Performance not affected by water or mud
Forms a three-way loadable mid-rope loop

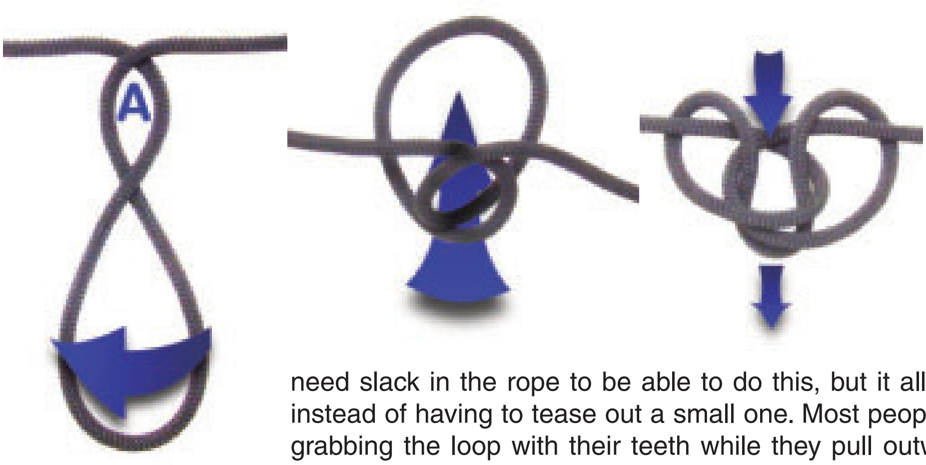
Description

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.

How to tie

There are several ways to tie the ABK, all end up making three loops and pulling one through the others with a nifty twist. Which method you use is entirely down to which you can remember, but the first method allows a larger loop to be made from the start, whereas the second makes a fist-sized loop every time.

Method 1 : The twirly flop



Taking a handful of the rope, make two twists as shown in the first photo by twirling one side of the rope in your fingers. Keep an eye on the *middle* eye, labelled 'A'. Take hold of the bottom of your double-twist, pass it up behind the knot and flop it over the twists. Then poke the loop through the middle eye, pulling it down to form the final loop. You do need slack in the rope to be able to do this, but it allows you to make a really large loop instead of having to tease out a small one. Most people tend to pull the knot into shape by grabbing the loop with their teeth while they pull outwards on the two ends of the rope - remember the ABK expects the rope to be loaded end-to-end and not in parallel.

Method 2 : The finger poke

Lay the rope diagonally across the palm of your hand, then wrap it twice around your fingers, working towards your

13. Tape Knot

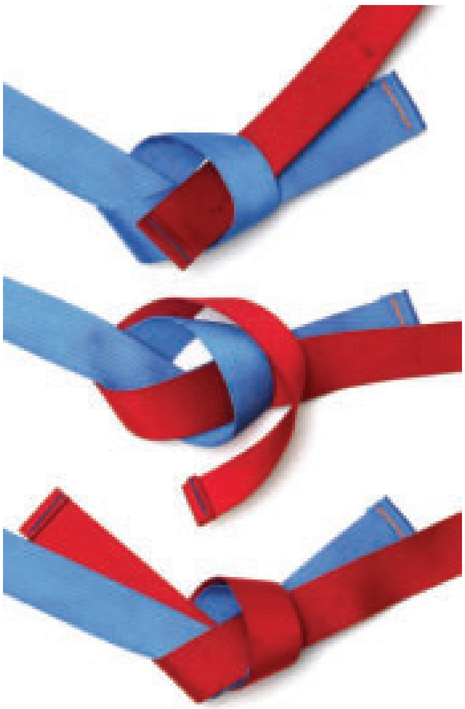
TK

Breaking strength: 45 - 65 %
Extremely hard to release after loading
Works only with webbing

Description

The 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. While we don't actually like the idea of tied slings, many teams prefer the flexibility of making their slings to length and threading them through holes. In the USA, knotted slings are extremely common but in Europe they tend to be used only when you can't find or afford a sewn one. We'll debate this in our chapters on anchors and belays, but as a lot of you *will* be American, here it is.

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. At least 10cm of tail should be left on both sides. There's some talk of backing up the Tape Knot by whipping the tails around in half-fisherman or overhand knots, but once the first pull sets the knot it will not move, so they're pointless. When we've tensile tested TKs they fail at about 50% like they're supposed to, but adding extra finishing touches make no difference. The weakness is the fact the knot pinches the webbing that's emerging from it, and that's where the failure happens. The only reason you'd want to fasten the tails is if the knot was left loose - and you're *not* going to do that.

Applications

Joining webbing of identical width. Should never be used to join unequal webbing, ropes or to join ropes to webbing, as in these cases the knot is very weak and prone to slipping under load. There's a thing called the Three-layer Tape Knot or the 'water knot splice', where one side of the knot is a plain single piece of webbing, and the other side has two ends in parallel - usually the two ends of a second bit of webbing, so the goal is to tie a loop *onto* the end of a plain section of web. **We don't like it**, but we can't precisely say why. There's certainly some scary results from our tensile testing where the middle section just slithers out at 20%, but some days it works fine. We're still playing.

Potential drawbacks

After heavy loading, especially in soft tubular webbing, it can be impossible to release - which is annoying if you tied it intending to get your webbing back at the end of the day. The large range in strength is down to the material it's tied in. Tape Knots are used on webbing, and different polymers, tape widths and styles (flat, tubular, etc.) make a huge difference to the strength. In slippery polymers such as Vectran or HMPE the knot performs very poorly. The best figures of 65% came from 25mm twinflat nylon tape.

See also: climbing shops that sell webbing sewn into pretty loops of all shapes and sizes.

Forces & friction

In terms of cave rescue, we spend 90% of our time trying to lift something - and that's different to the surface and industrial teams who start high and lower their casualty back to the ambulance. We also operate in a far from ideal environment where equipment is covered in mud, ropes rub against rocks and the angles are never quite right. It all ends up with our rigging suffering a great deal from the effects of friction, which for a 'lowering only' team is often thought of as a friend not an enemy! It's not just that there's a lot of it, the difficult job sometimes is to work out where the friction is hiding when your hauling party complain they can't haul, but your rigging looks OK.

The normal caver solution to friction is to pull harder, and when you're dealing with little rocks or one bodyweight that can be fine. With a 200kg load on the system, pulling 'harder' is not possible without overloading your anchors or snapping a rope, and so we really have to get this friction problem sorted before it attacks us in the middle of a rescue. In this chapter we'll work through the goals and theory of hauling so we're ready for the real-world systems later on - but **please** don't skip through this section as 'boring math' - unless you know how and why a hauling system or a pulley works, you have no clue what you're doing with them. Any fool can make a collection of pulleys. Only a rigger can make the **right** collection of pulleys.

6a: What exactly is friction?

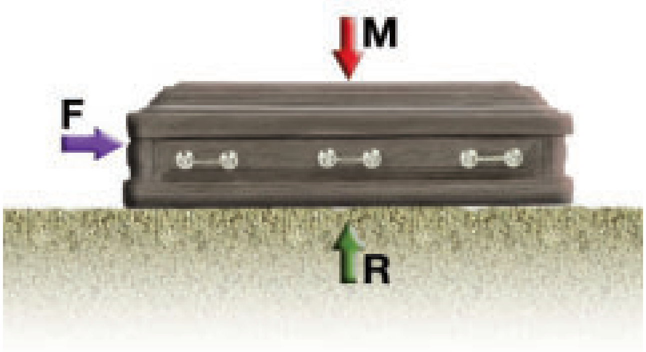
Apart from gravity, friction is the biggest factor in any hauling system. A poorly-planned system to lift 100kg can waste 500kg in friction before anything even moves! All our equipment has *some* inherent friction if a rope moves through it, from the small (in a pulley) to the enormous (in a belay or descender). It's not just about picking things with small friction - it's about putting things in the right place and the right order so the friction works to your advantage and not against you. Pulleys, descenders, belay devices and even the rock itself all act through friction, so we'd better get to grips with what it is!

To be exact, there are two types of friction - static and dynamic. Static friction is the force needed to start two things moving past each other, and is down to the surfaces binding together (stickiness, roughness, etc). It's why, for example, if you press a finger hard against a sheet of paper then try to slide it, you have to put in a lot more effort to get it moving, then all of a sudden it slides. Dynamic (or moving) friction is the extra force needed to keep something sliding at a steady speed, and is usually a percentage of the load. If nothing's moving, then of course there's no frictional force to calculate! In our rigging we're going to ignore *static* friction as, for the equipment we're using, it's too small to be of interest. Dynamic friction, on the other hand, is very important indeed.

For the next few pages we're going to be talking through basic mechanics, and forces. If you slept through math and physics at school, or are just too old to have covered Newton, then this is worth reading. We don't expect that a cave rescue team is going to teach rigid body mechanics at MIT, but your entire rigging system is one long fight against friction so it **really** helps to understand your enemy! Even if you only read this section once, we hope it'll stick in your brain and save your ass in the future.

For our work we're thinking about ropes moving through devices, sliding over edges and running around pulleys, but let's introduce friction using something you hopefully never have to cope with - sliding a coffin across a parking lot.

The coffin has a certain mass M, let's say 100kg. He wasn't in peak health you know... and gravity acts straight down so the coffin pushes straight down (the force is called the action), and the ground pushes back with the same force - which we'll label as R as it's called the reaction.



Newton (grumpy guy in a wig. Apple tree...) insisted the sum of the action and reaction has to be zero (so our two forces have to be equal and opposite) or something will move, and the coffin ain't sinking, so $M = R$.

Pulleys & descenders

Now that we've talked about friction and how it works in things like pulleys and descenders, we can get our teeth into picking the best ones to use. Pulleys are by far the most important item in your store as without them almost nothing is going to work - but the table in the last chapter has already shown you that some pulleys are better than others!

7a: Pulleys

Normal cavers think of pulleys as strangely expensive toys for lifting their car transmission, but rescue rigging worships them. Placing pulleys in the right place, and selecting the right pulley, can make the difference between a single-man lift and 12 hairy salad-phobics struggling against an immovable blob of screaming human. All our hauling systems rely on pulleys both to create the mechanical advantage and to change the direction of moving ropes - they're so intrinsic to cave rescue that it's often said you can tell if a caver is in the rescue team simply by the fact he's got one clipped to his battery belt. In actual fact, this is not the case. Real cave rescuers are the ones with a pulley-shaped dent in their pillow.

At the basic level, a pulley is unashamedly simple - a wheel on a stick, round which you pull something long and bendy. It seems to do nothing other than reduce the friction, and it's reasonably good at it. Early wooden blocks hand-carved by sailors (cue the photo!) gave way to metal, plain axles inherited bearings, but they're still a wheel on a stick. The trick, of course, is picking the right wheel and the right stick.

Excuse us for treating you like a fool, but let's define the parts of a commercial pulley before we start. People have slightly different terms across the world, so if in another 90 pages we say "twin becketed minder" we'd like you to know what the Hell we're talking about.

- The 'wheel' of a pulley is called a **sheave**, and it turns on (wait for it!) the **axle**
- The side-plates are called **cheeks**
- The big hole at the top is called the **main hole**
- The little hole underneath (if present) is the **becket hole**, and a pulley with one is a **becketed** pulley
- A pulley with two sheaves on the same axle is a **twin** pulley
- A pulley with two sheaves in line is a **tandem**
- Pulleys where the cheeks are separate and only connected to the axle, so they spin around, are **swingcheek** pulleys. 90% of the pulleys you'll want are swingcheeks, as we'll explain in a moment. If the cheeks are designed with straight sides and are set close to the sheave so they trap a prusik knot, you have a **prusik minding** pulley or just a 'minder pulley'.
- Finally, a pulley with a very large sheave designed to pass knots is called a **knot-passing** pulley or a **highline** pulley (as they are often used for Tyrolean traverses, called highlines in the USA)

Single swingcheek pulley

Twin becketed pulley

Hardware & fabrics

This chapter handles the basic items every rescue relies on, but often get overlooked when planning and selecting kit. We've discussed rope, pulleys and descenders already. We're leaving harnesses, helmets and rubber boots to the team member's own wallet and preferences, so before we start building hauling systems we just need to cover the remainder of the team kit - karabiners, rope clamps, slings and energy absorbers.

8a: Karabiners

Before we even start, people will be debating the spelling. Karabiner or Carabiner. Well, the term originates from the German term for a hook to connect a carrying strap to a carbine rifle, and the German spelling is **karabiner**. We'll stick to that, if for no other reason than "have you got crabs?" is a medical question not a technical one.

Sport caving often uses snaplink karabiners, as they are simple, work under almost every type of mud you can buy, and save enough money to pay for a beer. *Rescue rigging shall use lockable karabiners for everything. No exceptions. Nada.* If there's one snaplink in your truck, you'll find a casualty hanging on it. We know that your standard-issue caver uses snaplink cowstail karabiners, but that's not the point - the gear your team uses will be holding rescue loads and injured people - snaplinks on cowstails are banned in an industrial setting for the very simple reason that a quarter-turn will unclip them, even under load. You don't get to do that to a casualty.

The first question when browsing catalogs or raiding sports shops is how do we want these things to lock? Screwgate, twistlock, triple-lock, pin-gate, quadruple-flange-lock-with-kitten?

Locking Method

Screwgates are simple and inexpensive, but anything with a thread will be prone to 'gunking up', and if someone overtightens the collar when the karabiner is under load, it can take a wrench to undo. Screwgates are still the best option for 'general team kit', as they are the only type you can intentionally leave unlocked, but be wary that some cheap brands are known to cross-thread or stick. Cheap ain't always a good idea.

Twistlocks use a spring-loaded collar, usually making a quarter turn to lock the gate, but there are a few (like the Petzl Vertigo) with a sliding collar. They are often used on cowstails where rapid lock-unlock sequences are needed, and some teams like them for their general kit as they always lock themselves (no need to remember?) - but they have fragile helical springs. Springs hate caves. Cleaning and lubrication after EVERY USE is essential, or they slowly disintegrate.

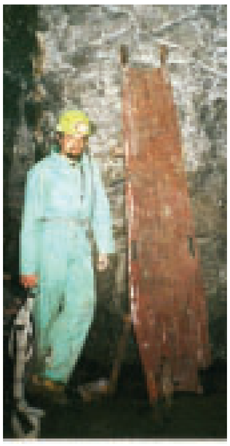
Beyond this, we have 'security gates' - triple-locks, pin-locks, button-locks. Usually a screw or twistlock karabiner with an additional action (lift, push, pull, etc.) to guarantee that the gate cannot open itself. They all have internal springs and levers, and are very prone to deterioration in underground conditions. Don't even bother - security gates are for people without the brains to rig properly.

The locking system of a karabiner has no effect on gate-closed strength - that's entirely a matter of the direction of load. If team members really want to leave their cowstail karabiners unlocked then that's their decision - but it's not acceptable for any karabiner that may be incorrectly loaded (for example on a descender) or for any part of the rescue rigging. It's not only very easy for something to rotate and unclip the casualty, it's happened over and over again.

Finally, remember that being 'locked' is no excuse for loading the gate of a karabiner. In several recent abseiling deaths a locked gate has been levered open by a descender, snapping the locking sleeve in the process.

Stretchers

All rescue teams will have a stretcher, but if your casualty has earrings all you need are nails and a plank.



Mine stretcher from c.1900, used in the UK and RSA.

This chapter doesn't set out to rubbish whatever stretcher you've been using for the past decade, nor does it try to make you buy a particular model. We can't avoid talking about specific examples, and what we may think of them, but we're really interested in the **style** of a stretcher and the quality of the construction, not the name on the bag.

There certainly isn't one all-purpose ideal stretcher for rescue, and despite teams trying to invent one for at least 50 years, you probably will end up needing two or even more, depending on the sites in your coverage area. Cave and mine rescue is certainly the most challenging form of stretcher work, and even in a routine recovery phase the casualty can be dragged through narrow passages (needing a flexible stretcher), lifted vertically up a pitch (needing a rigid vertical stretcher) and then carried to awaiting transport (needing a conventional litter). Injuries expected in cave rescue are usually orthopedic, with a high ratio of lower limb, spinal and pelvic fractures. The recovery phase can take many hours, so the stretcher(s) must be as comfortable as possible and allow medical access and monitoring. Then, of course, we have the fact the caver entered a hole only a few microns wider than her own shoulders, and has to come out the same damn way As a result, cave rescue stretchers are usually built specifically for the job.

9a: Basket litters

Extremely common in surface rescue and with industrial/fire/EMS teams, the basket litter is a rigid coffin-shaped tray, in which the casualty is strapped. Surface models are often made from metal with open mesh bases, so they don't catch rainwater and don't present a surface for wind or helo downdraft. Naturally, a metal mesh frame is as useful in a cave as a Styrofoam hammer, but there are polymer basket litters that have some potential, as they can be dragged over rocky or muddy ground without snagging.

Being totally rigid, the basket litter is useless in a truly confined passage, and is realistically reserved for rescues in vertical pitches wide enough for a horizontal lift, or in mine rescues where the passages are human-sized and the litter can be carried in the normal way. Some litters fold or separate into halves, but you can't really do that when there's someone in it. Hinged litters also all bend vertically, when what you really want in a confined rift is one that bends horizontally!

Commercial designs (like the Ferno above) really aren't designed for confined caves, and teams, especially in Europe, have resorted to custom-fabrication. The "mummy" stretcher, designed, produced and made famous by the Austrian and Swiss cave rescue teams, is a GRP coffin with the smallest dimensions possible (usually this means a head-and-shoulders shape to the top, hence the name), and with curved corners, lots of drag handles and reinforcement to the bottom. They usually adjust for height with a sliding junction, and if you want one yourself, we suggest you go talk to someone local that makes canoes.

The major reason for using a basket litter is patient access and release - despite being strapped into the thing with more webbing than is normally allowed outside a fetish club, individual sections can be accessed as there's no overall cover, so if the patient starts to bleed you can get at things. If they get cramp, you can let them wriggle. Critically, if you're concerned about posture for a medical reason (suspension trauma, fainting, cerebral compression, hypothermia etc.) you can allow the casualty to sit up, or get out, very quickly. It's usually perfectly possible for a litter to be raised (horizontally) while the casualty is sitting up inside it. Baskets are also damn good carrying trays for team kit, and the commercial designs can be helivaced - most military helicopter teams will only hoist a stretcher that has military ratings stamped on it, and it's a pain to have to swop on a hurricane-swept clifftop.

Down a cave, however, we need a better option. A **way** better option - but shame not everyone knows!

Anchors

We've discussed ropes, knots, karabiners, stretchers, sheep, webbing, forces and medicine (OK, we've not done sheep yet...) - but sooner or later we're going to have to talk about what to attach stuff to. It helps. This chapter is intentionally quite a way into the book, as to fully understand how best to use anchors we needed to cover the knots, the equipment and what we want to do with them first.

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 something heavy. Belays are the subject of the next chapter, in case you're feeling impatient.

Rescue riggers will often find in-situ anchors placed for sport caving (resin hangers, expansion bolts, climbing chocks, scraps of rope, etc.) and reliance on these rather than installing new anchors is a question of speed, strength and experience. You need to know not only how strong the anchor is *supposed* to be, but how well it was actually fitted. Clearly there is less concern if a rescuer knows the history of a bolt and can vouch for its security, but anything left in-situ will be abused by those using it, and the environment it's living in. There are countless examples of testing programs where 'amateur' anchors are tested to destruction and found to be massively weaker than people thought - mostly due to the quality of the rock or a basic mistake by the caver.

Surface rescue teams can always resort to a 4x4 or large section of the countryside, whereas in cave rescue the 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 attractive option. The only real place that the 'use the truck' idea works is when your team are hauling someone up the entrance pitch.

If we haven't got a perfectly-placed rock pillar or 15,000 pounds of railway track, you'll have to make something - and that can often mean drilling a hole. Obviously in every situation the strongest possible anchor system would be a massive array of resin-fix bolts distributed around the area and linked together, or a huge rolled steel beam 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.

Anchors need to be ***sensible*** compromises of perfection and reality!

Working in artificial passages (mines and quarries) or where cavers have done that thing they like to call "a bit of digging", the usual anchor point is *something heavy*. Clearly the safety of the anchor is based on the skill of the person choosing it, and whilst a 12 inch valve bolted to five miles of cast iron pump pipe (see photo) is pretty much a given, there are many times when the anchors are borderline – wooden beams, scaffolding, big broken chunks of stuff. We'll discuss these in detail in a page or two, as they need a lot of thinking about!

But before then, time for a trans-Atlantic moment!

Through-bolt systems

Also known as stud anchors, these use a solid threaded bolt that goes into the hole and also sticks out so a conventional hanger can be attached using a nut. The bottom of the bolt incorporates an expansion system - in some it's the same calking idea as used in sleeves, and a conical wedge is pushed into a set of fingers, but usually there's an inverted cone lathed onto the end of the rod and above that is a collet. Under tension the collet expands and the bolt grips the rock - so these are also sometimes called a 'non-calking stud'. Of course you need to drill the hole first, and in most cases it's a lot deeper than the sleeve-based designs, but the idea behind non-calking through-bolts was that if you remove the hanger and hammer the bolt *inward* you can release the collet and get your bolt back - either to take home and cherish or to inspect for corrosion. The drawback of non-calking studs is that to set them you need to apply a specific torque. Hilti produce a specialist high-strength through-bolt (the HDA-TR) with an 'undercut' expansion system that digs into the side of the hole, providing excellent grip even in very hard rock and with dynamic loads. The fact the entire diameter of the hole is filled with the bolt and the way the collet is progressively expanded means through-bolts are a lot stronger than a sleeve insert of the same size. You should still be using at least an M10 though, to allow that hefty spannering.

All-in-one Expansion Hangers

This beastie is rarer, and pretty much the only widespread sales are of the Petzl models. They simply combine an expansion-sleeve insert and hanger into a single item, with a pin-drive system instead of a threaded bolt. They're designed to be a little more reliable than the 'separates' system as there's no guesswork about torque, but their main selling point is they can't be stolen - an important point on popular rock climbing crags, but pretty daft underground in Lechuguilla. Unlike with the other expansion systems, the All-in-one can't apply tension to compress the hanger against the rock face, so they make up for it by having a hanger that fits over the entire diameter of the insert.

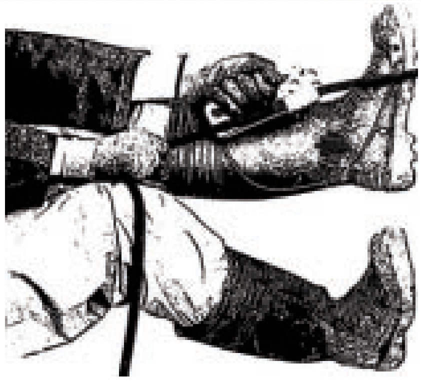
Drawbacks of expansion anchors

All of the anchors based on expansion suffer in long-term placement because the hole isn't waterproof. Even with stainless steel you can get corrosion, and in some countries ice forming inside the hole can lead to frost shattering. With sleeve-and-bolt systems there have been several injuries caused by very old installations, where cavers repeatedly fit and remove their own hangers, as the thread inside the sleeve is worn away. Probably the most common 'mistake' in the use of threaded anchors is underdrilling - the strength depends a lot on the correct depth of placement, and even a few millimetres too short can halve the strength of the anchor. The photo to the left shows a typical "caver installed" expansion anchor, in this case an M8 self-drill that's about 10 years old. A combination of over-enthusiastic setting, side loading and corrosion has cracked the rock, leaving about 3mm of the sleeve visible - there goes at least 50% strength!

Expansion anchors also apply a preload to the rock - even without anything hanging on them, they're pressing outward on the hole and so the rock is under stress. The more aggressive the expansion, the more preload stress is applied - and rock can only take so much before it breaks. It can sound contradictory to some people but an expansion mechanism that opens a long way is often weaker than one that only opens a little!

Probably the worst thing a rescue rigger can be faced with is a home-made anchor - a random offcut of metal and a rusted-up bolt. If the installer's cut corners with the hanger then you can assume they've done the same with the sleeve or through-bolt as well, and many of these will use mild steel "DIY" fittings designed to hold up your kitchen cabinets. In the photo someone has added a new resin anchor, but foolishly didn't remove the old one!

Simple hauling

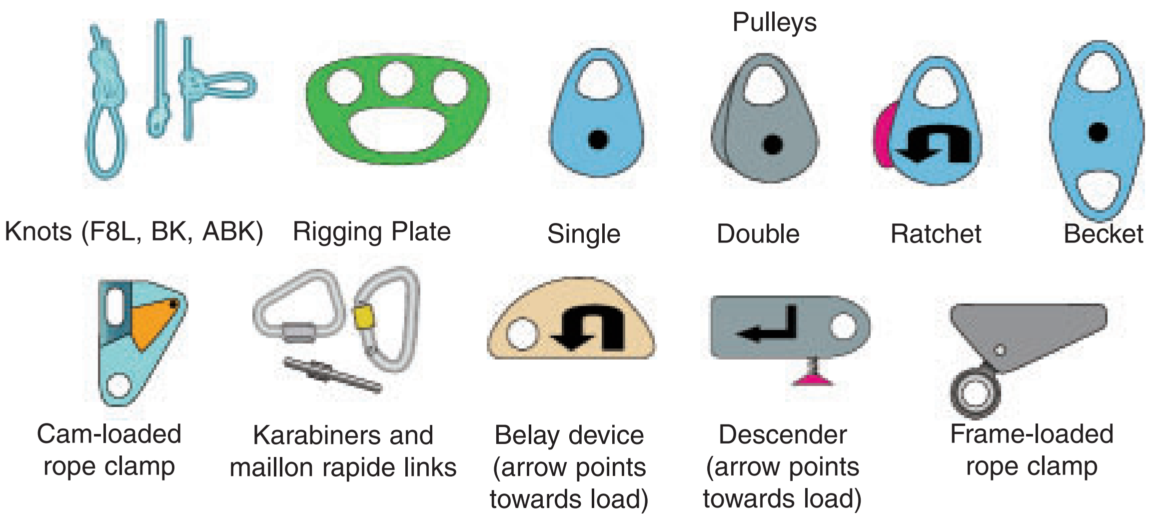


If you ask what the fundamental difference between 'sport caving' and 'rescue' really is, then apart from the blood and screaming it's the hauling systems. Sport cavers are used to self-propulsion on string, and can get themselves places humans were never intended to fit. Depending on where they live, they may also shift a lot of large objects - caves filled with mud and boulders are inhabited by cavers with more equipment than the average diamond mine. They construct mine cars, sink shafts, blast through rock and clear the debris like no other lifeform on the planet. What they *don't* often do is care they're knocking seven bells out of the stuff they're dragging about. 'Caver' hauling is about big ropes, vast amounts of ironwork lovingly welded together over months, and many many people.

In contrast, 'rescue' hauling is about high-efficiency, fast setup and *extremely* gentle handling of the load. Certainly it helps to have a mile of railroad in place before someone breaks their ankle, but life isn't that nice. Surface teams often spend a lot of time dealing with lowering systems, but we're going to bounce through them real quick and get onto hauling instead. Our quarry is in a quarry. The next chapter will expand on these basic ideas for the gnarly jobs you get some days, but we expect that 90% of all your rescue rigging will be based on this chapter.

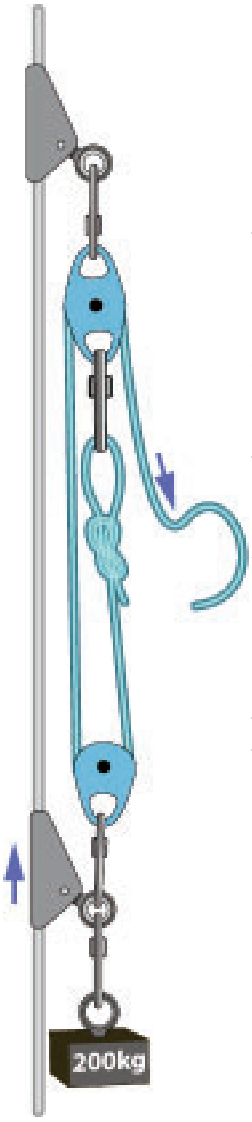
In the previous five chapters we've been reviewing and selecting from hundreds of commercial devices, from karabiners to stretchers. Apart from a brief mention of rope capture devices and how ***not*** to build them, in the next three we're forgetting about them entirely - because we don't know what you bought! Instead all our explanations will talk about "a descender" or "a pulley" and we leave it up to you to see which device would actually be the best choice. If we're talking about a descender that has rope taken in through it, then you know from chapter 7 that rules out some styles and promotes others.

Our diagrams will use generic symbols for each type of device, so you can stick a page up on the team notice board and folks won't say "no fair - we can't build that without an I'D and all we have are these twenty three racks!".



We also won't make much mention of anchors, not for a while at least. If we draw a pulley connected to an eyebolt it doesn't mean you can't use a sling around a strut or whatever else you can knock together in the time you've got available and given the state of the rock some fool is trapped under. It's why chapter 10 was so long!

12l: Inchworms

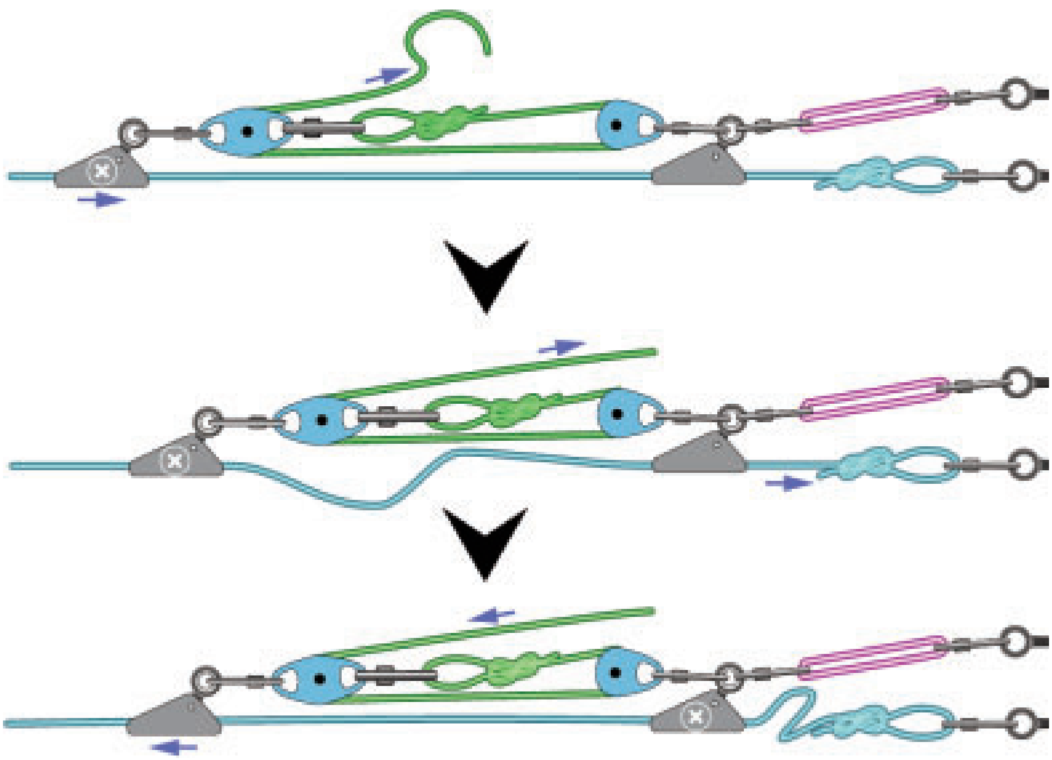


If you turn one of the rope clamps on a jigger upside down so they're both pointing in the same direction and whack it onto a fixed rope with the load connected to the bottom clamp, then it will climb. Hauling in the pulleys, we'll drag the bottom clamp up while the top one grips. Letting out the rope, the bottom clamp supports the load while you push the top one higher - you've made your jigger into an inchworm. It's equally possible to lower with one, as you can walk the rope clamps back down one at a time just as if you were doing SRT reverse-prusiking.

The inchworm system is used a lot for workplace confined space rescue as you can fit one onto an SRT rope and haul both yourself and your casualty out, even in a shaft so narrow you can't use your legs. We don't expect to need the same idea in cave rescue, not least because our ropes are moving, but the concept of cranking a tensioned rope through a hauling system is worth thinking about!

Take the example of a fixed rope (maybe an SRT line) on which you've got no belay devices, no descenders.. but a casualty that needs to be lifted. It's probably an injured team member. You have no end of pulley systems in your head, but it's the rope capture issue that can confuse you - how do you get the rope off the anchors and into a ratchet pulley or descender?

Well you don't have to if you've got an inchworm, because the two clamps are perfectly happy on a tensioned rope. The diagram shows what you'd do - with one rope clamp connected to the anchors and the other sliding back and forth to haul in the line. The rope clamp that's holding the tension is marked with a cross, and all the rigger needs to do is pull the SRT line through the rear rope clamp each time the inchworm contracts. Sure, you could have used the same equipment to build a jigger, haul up some slack and fit your rope capture device or you could've abseiled down and connected a new rope - but isn't this a lot more elegant?



12m: Load release hitches

It's been a while since we courted controversy, so let's talk about the load release hitch! These are designed to allow a fixed link to support a load but to lower it on demand by paying out rope or webbing through an HMS knot, and they've been made popular by a well-known rigging school but have had little impact in cave rescue. The concept is nothing new, and is a variation on a Mariner's Hitch (a load-release knot first used in the days of tricorn hats and pirate galleons).

The first thing to say is that there are lots of different types of load release hitch (LRH), and not a lot of agreement on names. All include an HMS knot somewhere in them, but the way the rest of the rope or webbing is routed varies. They differ in performance, but not by a lot and we don't intend to use them as much in cave rescue as surface teams tend to do - **certainly not as an energy absorber**, which is something promoted by other texts.

When tied off, an LRH can look horribly complicated with wraps and turns and tucks all over the place - in webbing it's worse than in cord, but you can still feel confused. The main reason for this is the tail end - since the LRH is designed to start short and lengthen when needed, it has to have a long tail to start with - typically up to five metres of it. Once the core of the LRH has been created, riggers then tidy away all this spare rope by whipping it into a noose, knotting off chains of overhands, or coiling it and sticking it together with elastic bands - whatever they do, then result is a complex bundle of cord even though the LRH inside it is quite a simple idea!

In the sequence below we're using 8mm accessory cord - about 10 metres of it - to make an LRH that's about 60cm long. We've started by fixing the cord to the bottom karabiner with a barrel knot, something we've changed from the standard "Figure-8 loop" idea as it's more compact and tighter in slippery cord.

We then loop the cord once between the karabiners, making a 3:1 B+T system, and finish it with an HMS. This is the core of the LRH completed - and you can see it being used to lower in the photo above.

A lot of the different patterns of LRH then diverge on what we do with the rest of the cord. The sequence shows a "Radium" LRH, where we tie an overhand knot around the loops, followed by a second overhand knot using the tail of the first one. In the far right photo of the sequence we've tidied up the tail by wrapping it around the LRH and tucking the end inside - just like you'd tie off a coil of rope in the old-fashioned 'mountaineering' style.

The reason for using such a long cord to make a short LRH is that unlike a conventional belay device or descender, we can only lower off what we've got, and we have the added drawback of a B+T pattern to the rope. If we're trying to release the tension on a rope that has two metres of stretch, then the LRH will need to have at least six metres of tail to start with! Making a self-contained LRH with more than ten metres of cord gets messy, but if you need a really long one for something, you can always keep the tail rope in a little bag clipped to one of the karabiners!

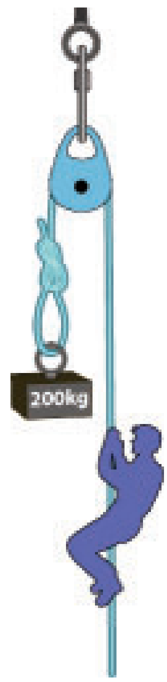
Complex & SRT rescue

For a lot of the hauling on a rescue, simple direct-pull rigging with a 3:1 or 6:1 is adequate. Sometimes, however, the cave hates you more than that. Pulling without room to put people. Hauling past deviations, or reaching into your rigging to drag out a team member that took it upon themselves to screw up.

13a: Counterbalance systems

Most times your hauling system relies on people pulling a rope using their arms, or clipping a rope clamp to their cowstails and walking backwards across a bleak mountainside. You certainly have control and it's simple to set up, but you're not using your hauling party to their maximum advantage - you're not using their bodyweight.

We're not going to consider the hauling system in this section, we'll assume you build one using the techniques from the last chapter. Here all we care about is the counterbalance rigging that goes on afterwards.



Talk to sport cavers and they'll normally describe a counterbalance as something like the diagram to the right - a load is being lifted using a rope that runs over a high-angle deviation. On that rope is a suitably large person (whom everyone calls the balance man, but at the time they're acting as the balance weight, and there's no reason why she can't be female), and their job is to steadily ascend the rope, drawing it down and so lifting the load. It works quite well provided the load is lighter than the balance man, but you still have both the weight of the load and the weight of the balance man acting on the top pulley. This basic pattern is often used to shift equipment or rocks that are too heavy for a hand-over-hand lift, but lighter than a bodyweight - the only real concern is that lifting is easy, but lowering requires the balance man to reverse-prusik down the rope, something that many people find difficult. You also clearly can't just leave the load parked in mid air and walk away!

In rescue we assume the load is far too heavy and too important to be lifted using this basic method; you'd obviously need more than one balance man on the rope, and that requires them to be stacked vertically - not easy for the person at the top! We also don't want to rely on team members built into the system as if the load changes for some reason it can go horribly wrong. Instead, we use counterbalances to **reduce the work done by a conventional hauling system**, and make sure that all of the control remains with that system - the counterbalance helps but disconnecting it will not make the load move. Changing the weight has to be allowed (both increases and decreases), so the counterbalance has to be adjustable. We will eventually need to remove it entirely so the load can be transitioned off the pitch, and finally we need to make sure the balance man is safe.

You're aiming for a balance weight that's a noticeable amount *smaller* than the load being lifted, as it's important to avoid the situation where the advantage switches over and the hauling system becomes slack - most of the time it's best to aim for at least 20kg difference, but when lifting a full rescue load the reality will usually be a single bodyweight of about 100kg against a load of 200kg. It's still going to help the hauling team even with such a large difference, and it can be a sensible idea to keep the balance weight as small as you can, to reduce the forces on the top deviations. It's also a great deal easier to manage the system when only one person is involved.

So you install a rope that runs up from the load, over a pulley or two, then hangs down. It doesn't have to reach the ground at this stage, but it should certainly be longer than the distance of the haul! You have two choices for where to put the balance man - either below the load on the floor, so they ascend the rope but (in theory) stay within a few feet of the floor all the time, or up in mid-air someplace accessible - but it's extremely important to make sure they are never too close to the top deviation, as we're about to explain!

In many cases we see the balance man being connected to anchors, usually via cowstails or slings, so they physically cannot move beyond a limited range of heights. This prevents a floor-dwelling balance man from climbing up and risking a fall, and of course protects a mid-air balance man from the nasty side of gravity. **Well, we're going to have to change that**. The reason is simple - the balance man is SRT-ascending the rope, so is connected to it using a chest ascender with teeth. We know to our cost that these styles of rope clamp can sever the sheath at very low forces, so we really don't want to hang the entire rescue load *and* the balance man off one set of teeth.

Traverses

Hauling has been done. You're a living God in the subject, and nothing - not anything, will defeat you.

OK, so your stretcher arrives at the end of the mine passage in the photo. It's a 90ft drop to water, and the only places to stand are a few bits of rotten wood and a rusty two-inch water pipe snaking off towards the exit. You have two hundred feet to cover, and the medic is looking worried.

All you have to do is get the damn thing sideways before someone dies.

Still feeling confident?

This scenario happens every day in caves and mines, where your casualty has picked their way along a rift or danced like a pixie across paper-thin planks of wood, then decided to ungraciously hurt something. The only way they're going to come out, and probably the only way your team is going to get in, is to build a loadbearing traverse line and shuttle everything along it. Now it's not physically difficult to get a bunch of ropes strung across something like the passage in our photo, but without a lot of seriously careful thought the forces in your equipment can reach several tonnes. If your ropes snap and your rock anchors explode, you don't really expect three rescuers, the casualty and the stretcher to be saved by that water pipe...

14a: The knotty traverse

Traverses come in two breeds, and one is knotty. It has knots in it. Hardly a revelation, but for cavers moving along a rift at high level, keeping away from an unsafe floor in a mine, or just working along a sheer rock face to avoid getting their hair wet, the idea of clipping your cowstails into a series of anchors and a rope is trivial - you take your string, tie a butterfly knot whenever there's an anchor, and haul your ass back and forth. Passing each anchor doesn't even seem to be the hard part, as you have somewhere to hang from while you leapfrog karabiners about. Doing the same thing with a stretcher, or even with a casualty in a spinal splint, is a lot more fun. It's perfectly possible, but whether it happens smoothly or whether it turns into the biggest box of squirrels you've ever run away from depends on some very careful choices of equipment beforehand. This isn't one of those "arrive and make it up" tasks, this is all about following a plan.

If we're able to design the traverse, even just a little bit, then we'll try for:-

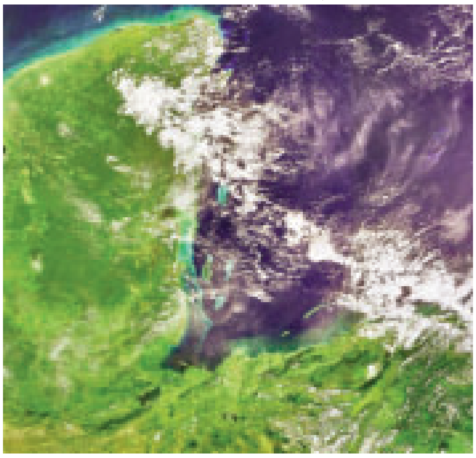
- As few knots as possible
- A horizontal or downward slope to all the sections

For many teams, transporting a single-point load (such as a casualty in a harness or a vertical stretcher) along a knotty traverse relies on the idea of two adjustable jiggers (replacing the cowstails a caver would use). When a caver passes a knot, they clip their second cowstail into the new section of rope and remove their old one, but there's an almost unconscious action to lift their weight so they can unclip. You can't expect that to happen as easily with a casualty, so the solution is to make their cowstails into tiny hauling systems. No more than a 3:1 is needed, and in most cases a 2:1 is fine - you're only lifting one bodyweight and only by a few inches. It's important that they can also lower as well as lift, so probably the easiest solution is a 3:1 block-and-tackle using a Grigri - we know it's not actually a 3:1, but it's good enough!

Special rescue

The 'normal' rescues we are dealing with in LOAL2 involve going down a hole in your locality, extracting a grateful but moist caver and traversing quickly to the bar. In this chapter we're looking at the two exceptions to that rule - rescue on expeditions and lifting of overweight things like livestock.

Yucatan peninsula © ESA



15a: Expedition Rescue

Cavers walking round the back of the clubhouse and dropping down a hole is the standard way to 'go caving' in many countries, and cavers spend most of their hours underground in their local area, digging out crap and fighting boulders. When they get stuck, the rescue team are usually already in the local bar and can handle the whole thing before the froth has settled on the casualty's beer.

Expedition caving is a different game entirely, and it's why when a caver gets trapped behind the bar it rarely makes more than a line in a club journal. When a caver is trapped 15,000 feet below the jungles of Lower Xtenistania they make a movie about it. Sharon Stone stars as their mother.

Expedition rescues have to rely on the team and their 'sport' equipment as a rescue team simply isn't going to arrive. Unlike what we've been doing so far, we can't get a pulley from the truck if the team didn't bring one, and if there were two cavers before it happened, there's now one rescuer - if you're lucky. The same end goal applies - getting the casualty out - but you're going to have to modify your methods to achieve it. Caving expeditions, like any other remote adventure sport expedition, need to plan for emergencies and rescue just the same as they plan for provision of chocolate and local money. We don't mean that everyone should spend the trip of a lifetime scared of accidents and checking risk assessments, but we do mean that some of the funding, and some of the time, needs to go towards solving the unforeseen.

Teams for caving expeditions are rarely small - four or more in a party is normal, as if nothing else you have a lot of gear to carry, and everyone that could afford the plane tickets wanted to come. If we plan for a single casualty you should almost always have enough people left to perform a rescue.

Before the team get on a plane, they should have dealt with the first set of questions:-

- Does the region have any 'cave rescue' service, and if so how do you call them out?
- If not, will the police, military or local villagers be in a position to help?
- If not, visit the bathroom, and check if it's possible to get a team in from another region.
- Do people 'back home' know enough about the trip to help a rescue team find you?
- What medical evacuation facilities are there once you reach the surface?
- Can you call for help - do cellphones work, can you hire a satellite phone, is there a Walmart nearby?
- Has the region any specific medical risks (waterborne diseases, bats, venomous spiders, cannibals...)?
- Do you need vaccinations, and if so have you got them, and got them in time to be effective?
- Have at least two of your team got first aid or medical training?
- Have you obtained suitable first aid supplies and lots of interesting drugs?
- Will the interesting drugs get you arrested?

We're going to assume that your caving gear and first aid supplies will be adequate for the rescues as well. You're not taking a stretcher, but if you have enough ropes and bolts to bottom The Cave With No Floor (El Grotto del Bastardo Magnifico), you have enough to haul someone back out of it. They may not be entirely comfortable, but they'll be grateful.

Winches

Mechanical winches are rarely used underground for lifting casualties, as to be blunt they're not worth it. For surface hauling (raising people out of shafts) they're awesome, and for shifting cows and boulders there's often no other option - many large animal rescues wouldn't happen without them. A 'winch' is anything that hauls a rope using levers or handles or motors, and it doesn't have to mean it runs from a battery - capstan and lever-based 'hand pullers' exist, even though we're about to throw dirt in their faces. Winches that run off gasoline and lift a thousand metres on a tank are up there with lifetime membership of the Playboy Caving Club, but cost a little more than most teams have to spend - you can clear a thousand dollars on the best models. They're nothing new by any stretch, with the first 'motorized ascender device' or MAD being produced by Nevin Davis in the early 70's[16]- but commercially the idea of a powered ascender/winch never really went anywhere (people at work, who had the cash to buy them, never climbed out of shafts) - then the US Department of Defense got involved and spread around some pretty quiet but lucrative tenders for making a powered ascender for special forces ops - a single-handed high-speed way to get down to a window, chuck in a frag and skitter back up again. The result was a lot of investment from the big names in armaments, and some random patents, and then silence again. Delta Force inherited some toys, but unless you trained with them you'd never have known.

Only in the last few years have commercial designs crept out of the smoke, and even now there's really only two - but we'll get to that after we look at bigger (and potentially better) things!

16a: Styles of winch

When winches revolve, there are two styles they can fall into. A drum winch acts like a cotton reel, and just winds the entire rope around it as it turns - the simplest is the windlass (shown left) where there's no gearing. Add a motor and gearbox and you can lift a house, but the problem of course is you need a bloody big drum for a long rope, and the diameter of the drum is very important to the speed of winding - as the rope builds up in layers, either the motor has to slow down or the rope speeds up! You can't extend the rope, or change it at the last minute, and drum winches are probably only ever going to be used in a pre-planned winching system (like the annual Gaping Ghyll winch meets in the UK), or as full-sized emergency winders for mines rescue (they come on a truck, with a team of men, and generally neither of these are the smallest examples you've seen).

We haven't got a great deal of use for drum winches in full-scale hauling, but short lever-cranked winches (cable pullers) with steel wire, sold for dragging boats and machinery about, can be extremely useful for clearing boulders - they don't risk overloading your expensive SRT rope, they have zero stretch, and can be adjusted by the millimetre. A cheap five-metre lever winch can be really handy to keep in the truck, but don't ever be tempted to hang a person on it.

Chain blocks, on the other hand, are to be avoided unless you work in auto repair. Unlike a cable puller, chain blocks usually have a ratchet and pawl clutch system to stop the load free-running down again, and when given chunks of cave to eat they often fail to do that very well. Chain needs to be kept lubricated, so your gloves and everything else in contact with it becomes gunked to the eyeballs. It's very heavy to handle and even a 'small' chain block with 20m of reach can weigh more than your casualty. These beasties, brilliant though they are for changing your transmission, should stay in your garage where they belong.

Equipment care

We're pretty much done with rescue ropework, and a little over a hundred pages have passed since the point we said it was difficult. You can call in your team, grab half a tonne of string and rescue a moist and grateful teenager, or more likely a piss-wet sheep. You slap each other on the back, trade tales in the bar about how utterly insane it all was, and how you not only looked Death in the face, but you pulled out his nostril hair.

Meanwhile the new guy is washing rope in the dark.

17a: Cleaning your gear

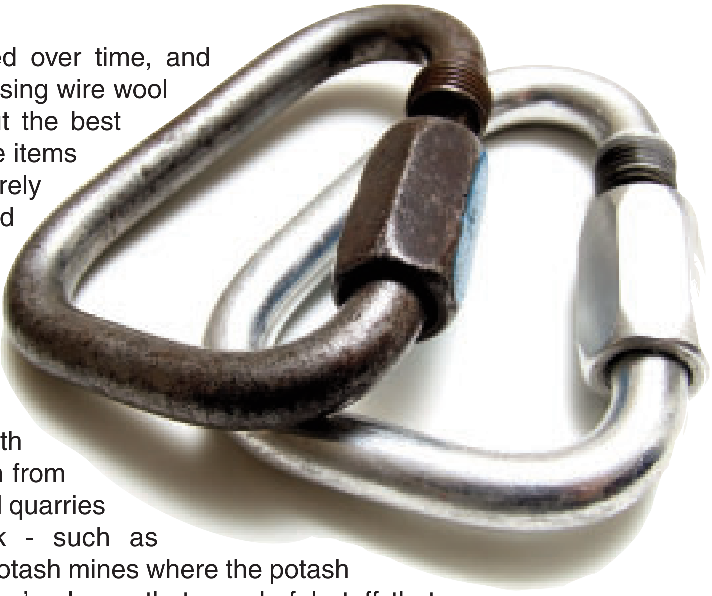
Cave rescue is a dirty business, and the equipment taken underground will be plastered with clay, mud and broken bits of rock every time. Some of the equipment we've used in previous chapters was chosen to be cave-proof, like the rack descender, but most of it was designed for sport climbing or industrial rope access, where manufacturers (strangely) assume there's no dirt. A lot of rope will have an instruction card that asks "keep away from dirt", and some of the more intricate belay and descender devices are impossible to clean (the Petzl I'D being a classic example). The upshot of all this is that your gear needs to be washed, both to keep it safe and to extend working life, and yet the manufacturers will hardly ever make it simple.

For equipment sold as PPE in Europe, manufacturers have to provide certain things on the information sheet, one of which is "cleaning instructions". They don't have to be sensible about it, just provide a statement. This means that most use the escape clause of "*this product can be washed by immersing in cold water*" but don't allow any detergents or cleaning agents to be used. That's fine if your harness has a floury fingerprint on it from your last donut, but pretty pointless for a rope that's been dragged through clay for ten hours! A large part of the selection of equipment for a rescue team is down to the friendliness of the paperwork - a long shelf life, higher permitted loads, and sensible cleaning instructions. We're not promoting any specific manufacturer, but you'd be well advised to check for things like this before buying into a brand - most products will have their instruction sheets available online these days and there's no reason you can't just ask them for clarification. You're unlikely to get permission to soak your ropes in paint stripper, but some manufacturers will admit to a little more than their standard text if pushed politely.

Metal equipment (karabiners, anchors, pulleys, etc.) can be washed in hot water, up to 100°C, and you can add detergents unless the manufacturer says not to. There's no real problem with scrubbing brushes or hoses, and sensible use of pressure washers - but of course you can't put them in a washing machine as they'll destroy it and themselves. You do need to be a little careful that any bearings are treated exactly as the literature specifies - pulleys, for example, can have sealed roller bearings that need to be protected from high pressure jets. Where there's a plastic element, such as on a rope clamp or descender, then pressure washers are a bad idea as they can be powerful enough to break into the surface. If your team has access to ultrasonic cleaning equipment then there's no reason why all-metal components can't be cleaned that way, but in water and not in solvent.

Once cleaned, metal items should be wiped all over with a light oil, and any bearings or pivots that permit lubrication should be oiled. Some bearings use polymer bushes that cannot be oiled, and in those cases adding lubricant will actually make the bushes deteriorate. Lubricating oils will not affect ropes or webbing, so leaving a trace of oil on the surface of a karabiner or pulley isn't a safety problem. It prevents rust while in storage, and to an extent acts like barrier cream - making mud and clay easier to clean off after a callout. We don't suggest leaving your equipment immersed in a bucket of diesel, but leaving it totally dry for months can be just as bad. Karabiner springs inside the gate need particular attention as they can harbour water - either dry them in a warm place for a day or so, or use a spray lubricant and water repellent like WD40 to displace any moisture.

Surface corrosion



Uniform corrosion of the surface of steel is expected over time, and usually presents no direct risk. Items can be cleaned using wire wool and lubricated using a protective oil (WD40, etc.) but the best solution is of course for the team to clean and store the items so rust never starts! Surface corrosion of alloys is rarely seen except where chemical attack is occurring, and should be a point to investigate - it can result from electrolyte spills or acidic cave water. Unless surface corrosion affects the operation of the item it would not require the item to be scrapped. Where protective paint layers or plastic covers have been damaged (such as on harness buckles) they are usually best left unrepaired as re-sealing can trap moisture underneath and lead to even more corrosion - but this time hidden from view. In some cases teams will be working in mines and quarries where the worked mineral presents a direct risk - such as metalliferous mines where the water becomes acidic, potash mines where the potash itself can rapidly destroy metal components, and there's always that wonderful stuff that comes out of the wrong end of a bat.

Galvanic and oxygen-differential corrosion

Where two dissimilar metals are in contact in the presence of an electrolyte (usually water with dissolved ions), the metals will create a small electrical voltage across the junction and aggressively corrode. One metal will usually remain intact and the other will be oxidised. Most of the time this is the explanation used for all corrosion in climbing equipment and anchors, and on a very vague level it's right - but galvanic corrosion isn't what's really driving the process with the sorts of equipment we're looking at - if it were, your alloy karabiners should corrode but the steel springs and hinges should not - and you know it's the other way round. Having surface layers of oxide (intentional or not), joining many different metals together, then putting some in water and keeping some dry, leads to a far more complex process where differences in oxygen levels also contribute to corrosion. The speed of corrosion is affected by chemicals in the water (trace metals from mines, calcium ions from the rock, acids from rainwater, etc.) and often the corrosion of one item (such as a steel rock anchor) produces reaction products that increase the corrosion of other metals they drip onto.

A steel object is usually predictably strong even when rusted - the strength depends on the remaining cross-sectional area compared to when new. Alloys are far worse, and effects such as stress corrosion cracking can occur where an alloy device is loaded many times (such as an aluminium bolt-on hanger). Corroded alloys can show a very significant loss in strength even when the visible damage seems unremarkable as the corrosion, on a microscopic scale, is often formed from very narrow but deep cracks. It's not likely to be a problem for equipment that's part of team kit, but for in-situ wire ladders or rock anchors, alloys can be fatal even to the cautious.

Seawater corrosion

Exposure to salt water is a serious problem for any metallic item. Corrosion is extremely rapid as salt water is a very effective electrolyte, but more dangerous types of corrosion (intergranular corrosion and stress corrosion) can occur where an item is exposed to salt water and forces are then applied to it - such as an anchor bolt used on a sea cliff. The problem manifests in both steel and alloy components, and even for supposedly 'rust proof' items such as stainless steel, seawater can produce rapid rusting. Items exposed to salt water (either from seawater or where artificial salt is present, such as on roads in winter) must be very carefully maintained and often need to have a drastically reduced lifetime. For an isolated exposure event the advice is to immerse the item in fresh water as soon as possible, soak for 24 hours, then completely dry and lubricate before storage. Never allow an item to remain exposed to salt spray for a prolonged period of time without frequent maintenance and inspection - many rock anchors near the coast fail each year due to corrosion, with fatal consequences for the user.