

Life on a line



A manual of modern cave rescue ropework techniques

Dr. D. F. Merchant

Published online at draftlight.net/lifeonline

©2002/2003

issue 1.3

Contents

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

PART 1

1. Introduction
 - a. The reasons behind this book
 - b. Rescue vs. Recreation
 - c. Rescue loads
 - d. Levels of rescue
2. Rope
 - a. Construction and materials
 - b. Performance
 - c. Choice of rope for rescue
 - d. Identifying fibre polymers by flame testing
 - e. Transport, care and storage
 - f. Breaking in new ropes
 - g. Time expiry and working life
3. Introduction to knots
 - a. Basic terms and theory of knotting
 - b. Permanent knots
 - c. Knots unsuitable for rescue ropework
4. 17 essential rescue knots
5. Anchors and belays
 - a. Loads on anchors during hauls and falls
 - b. Natural and found anchors
 - c. Props
 - d. Rock bolts and hangers
 - e. Ground anchors and everything else
 - f. Rigging onto anchors
 - g. Belays for rescue
 - h. Belaying equipment
 - i. Releasable belays
6. Pulleys
 - a. Types of pulley
 - b. The β factor

PART 2

7. Basic hauling
 - a. Introduction
 - b. Backups and safety lines
 - c. Lowering
 - d. 1:1 Armstrong hauling
 - e. Rebelays and deviations
8. Compound hauling
 - a. The A-block
 - b. The V-rig
 - c. The Z-rig
 - d. Converting a Z-rig for lower
 - e. Modifications and improvisations
 - f. Jiggers
9. Counterbalance hauling
 - a. Top haul
 - b. Bottom haul
 - c. Inanimate balances

PART 3

10. Advanced rigs
 - a. Traverses and Tyroleans
 - b. Combination pitches
 - c. High-ratio pulley systems
 - d. Winching and powered aids
11. EN marking, PPE and the law
 - a. Overview of CE/EN and PPE requirements
 - b. Testing, inspection and maintenance
 - c. Rescue exemption
 - d. Inspection and paperwork
 - e. Other standards
12. Rope testing
 - a. Working life and decay
 - b. Drop testing
 - c. Other tests
13. Contamination and disinfection
14. Training for rescue teams
 - a. Training riggers
 - b. Relationships to industrial qualifications
 - c. Training and assessment scenarios
15. The future of rescue ropework
16. References and other sources of information

This book is published on the Internet as a non-profit making venture and is freely available for download as three PDF files. Printing, copying and distribution of the book is permitted provided that no profit is sought or made from any aspect of said action, and that full copyright and credit information is retained with any extract or reproduction.

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

Dave Merchant, North Wales, March 2002

1. Introduction

1a. The reasons behind this book

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

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

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

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

The book obviously includes extensive testing and reviews of equipment from several manufacturers. I do not pretend that the lists are exhaustive by any means, and I have

intentionally concentrated on equipment in current use by cavers and cave rescue in the UK. I have no commercial interest or bugbear about a particular device or manufacturer, and any good or bad comments herein are based on the results of testing and experience alone. Equipment develops rapidly and by the time this book reaches you there will undoubtedly be another few sparkly anodised ways of spending money that we should have talked about. Such are the limitations of the printed word.

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

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

Disclaimer

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

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

1b. Rescue vs. recreation

Cave rescue is a complex process in detail, though from the viewpoint of a sport caver can appear far less confusing than it can to the average member of the public. However taking the widest-scale view of a rescue the process is remarkably simple: one or more casualties must be found and recovered by one or more cavers going into the same system and doing a better job than they did. Looking back to the early days of cave rescue in the UK (1950-1960) this was in many cases as advanced as things got. Cavers were rescued by groups of other cavers whose sole plan was to follow them down, find them and pull them out by some means that would be thought about when they got to it. Running a rescue in the 21st Century is a far more professional affair, as indeed it should be. However the pressures of a professional response come tinged with the issues of legal liability, safe working practices, insurance, training and competency... the list continues. Added to these 'internal' pressures on the rescuers are the associated external pressures from the media, regulating bodies and the need to provide all this with often inadequate

charitable funding. The results can often be that a team's legal and financial responsibilities are dealt with as required, but the internal issues of training, rescuer skill and confidence are left somewhat behind. The result is that team member skills relate to callouts and their sport caving interests (and hence personal experience) rather than the sort of national standards adopted by 'surface' emergency services. UK cave rescue has evolved over a considerable time and the legal issues shaping teams are a comparatively recent factor. I would not advocate a rigid national training structure akin to the Fire or Ambulance services as the caving world has always operated on a more individual basis. However it is likely that the modern world of instant-reaction media and litigious 'clients' may well force such a framework. This is already beginning, with legal requirements on team member medical qualifications coming into place as I write. This book was written to try and narrow this 'experience-based' skills range but is not intended as any form of national training manual. It would simply be useful for someone in a rescue team to be able to look up the strength of a knot or the friction of a hauling system without having to go to the levels of research I have found myself wading through...

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

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

1c. Rescue loads

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

must revise your methods accordingly. If you end up with 500kg hanging on a single line, you must revise your will to live.

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

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

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

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

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

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

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

The peak load on any single anchor point is 12kN

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

with spinal fractures, even immobilised, can suffer critical misalignment of the cervical column in a vertical fall of only 1kN. As a point of comparison a limit of injury for a caver falling in a sit-harness alone is between 4kN and 6kN.

The maximum expected fall factor is one-third

In caving it is rare to climb above the anchors, so fall factors are limited to less than 1.0 except in moments of madness. In the specific area of rescue hauling and belaying the systems are designed to prevent all but small falls, normally by the use of backup lines and redundant anchors. Small falls resulting from failure of pulleys, anchors or karabiners can result in drops of a metre or so before redundant components take over. Our maximum FF of $\frac{1}{3}$ reflects this fact and is used by several other testing programmes. It must be noted that for fall factors in excess of 0.5 with a full 200kg load very few components will survive.

The maximum steady loading on any component is 8kN

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

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

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

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

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

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

Reaction time to a failure or rope movement is 1 second

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

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

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

The Sudden Death Rule

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

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

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

1d. Levels of response

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

An underground rescue can be thought of in five stages:

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

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

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

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

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

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

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

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

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

full of unconscious caver. The rigging methods presented in this book relate to this recovery phase.

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

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

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

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

1e. Medical influences on rescue ropework

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

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

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

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

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

2. Rope

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

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

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

2a. Construction and materials



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

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

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

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

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

At this point I would like to *again* emphasise a point related to the use of braided terylene static rope, which unfortunately is still in common use by surface rescue teams, the Fire Brigade and other agencies. Irrespective of the age of the rope and the true strength it may retain, there is a simple and unavoidable argument why braided rope should never be included in cave rescue rigging, namely that of compatibility. Modern SRT devices (ascenders, descenders, belay devices and so on) are specifically designed and intended for use on kernmantel rope meeting the requirements of EN1891 or EN596. Using such devices (for example an autolock descender) on braided rope will lead to erratic and often

dangerous behaviour. Apart from the fact that the manufacturer will absolve all blame should the issue reach an inquest, you have created a system whose performance you do not understand. Trying to lower off a critically-injured casualty is not the time to find that your descender has jammed because a braided rope has been used. Hopefully underground rescue teams will not have this dilemma when operating alone, however it is something to watch out for when working alongside surface agencies.

2a1. Materials used for kernmantel ropes

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

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

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

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

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

Nylon

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

Polypropylene

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

Dyneema/Spectra

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

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

HMPE is used in webbing and accessory cord but has limited application in true rope, and the strength of the polymer is the main reason. Under tension HMPE has an incredibly low modulus of elasticity (stretch), and even at 50% of the breaking load a sample of HMPE webbing will probably only stretch by 2%. This low-stretch is ideal for industrial applications such as winching and lifting where 'bounce' is not wanted, but for climbing or caving the results of a fall onto HMPE can be catastrophic. As there is

effectively zero stretch in the system, the peak forces on the anchors, karabiners and the climber's body can be massive. If the metalwork in the system survives the forces, the climber will almost certainly be killed by the acceleration forces. This is one example where a material is almost too good!

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

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

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

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

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

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

Aramids

The aramid family of polymers includes Kevlar (a trademark of Dupont), Technora (Teijin) and Twaron (Azko). Famous for use in ballistic protection, aramid fibre has a very high strength and abrasion resistance, as does HMPE. However when bent against each other, aramid fibres have a tendency to cut each other. They are also less flexible than HMPE for a given diameter. Aramid can almost always be recognised by the

distinctive yellow/beige colouring of the base polymer as it is impossible to dye. Aramids have a slippery surface similar to HMPE, so can suffer from slither at knots. There is no published evidence of creep, but given the limited application of aramids in modern climbing and caving equipment it is probably safe to assume the majority of the time you will never encounter it (except in your bombproof abseiling gloves!) It doesn't have a true 'melting temperature' but becomes charred at ~450°C. It is very dense so sinks in water.

Vectran

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

2a2. Common chemicals and their effects on polymers

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

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

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

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

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

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

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

2b. Marking

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

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

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

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

2c. Flame-testing rope fibres

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

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

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

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

2d. Choice of ropes for rescue

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

There is a clear argument for using the largest possible rope diameter on the grounds that it is (a) stronger and (b) less stretchy under small loads. If this were the sole issue then all rescue teams would be using 13mm ropes, however caving equipment (ascenders,

pulleys, descenders) are often designed for a limited range of rope sizes. Examples include:

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

+ The Shunt and Grigri are only designed for use with dynamic rope

++ The I'D is available in two sizes, for 10-11.5mm ropes or for 11.5-13mm.

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

Rescue ropes should all be 11mm diameter

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

The choice between manufacturers is not an issue for this book. All recognised manufacturers produce ropes that exceed the current standards. Some include water repellent, some make ropes extra-flexible, and some make ropes in nice colours. Above all that, most UK rescue teams are funding-limited and so the best type of rope is the one that can be bought for the least money. It is however worth considering the purchase of some coloured static ropes for hauling systems, as it has been proved by the CRO and

others that operating dual-rope systems is vastly easier if the ropes are different colours. Anyone at any point in the process can understand what ‘take in on the green line’ means, but ‘pay out line one’ is as confusing as watching snooker in black-and-white unless you have put numbered tags at each end.

2e. Transport and storage of rope

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

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

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

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

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

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

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

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

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

In summary then,

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

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

2e1. Washing and drying

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

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

2f. Breaking in new ropes

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

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

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

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

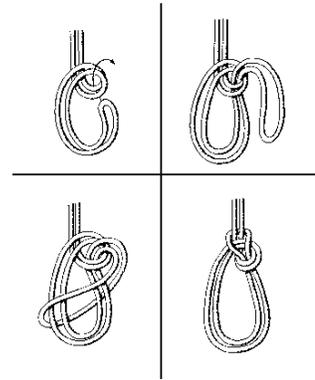
2g. Time expiry and working life

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

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

3. Knots

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



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

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

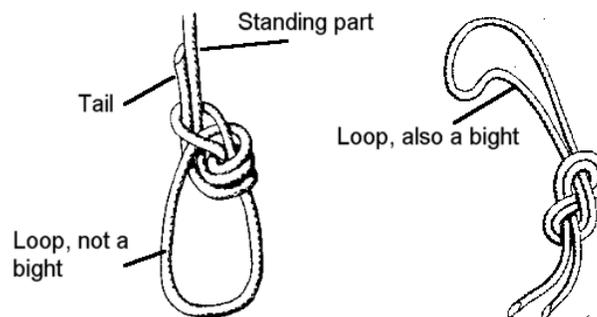
1. Is the knot suitable for the intended use?
2. Is it the strongest option?
3. Does untying or adjustment matter?
4. Will anyone else be able to understand what I’ve created?

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

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

3a. The elements of a knot

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



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

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

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

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

3b. Permanent knots

In this book a permanent knot is not one that stays in shape when you let go! Several studies in the USA and Europe have shown that for kernmantel rope in particular, if it is left in a knot for an extended period it can take on a permanent residual stress, even when untied. Almost every caver knows that when you untie a rope that has been hanging on a pitch for a long time, the section of rope that was in the knot retains a bent and curly shape. Few realise that this section is now significantly weaker than the rest of the rope,

and can remain so forever. Of most danger when tied in the middle of a rope (for example on a traverse line), long after the rope has been removed and reused and everyone has forgotten where the knots had been, it retains a point of weakness that could cost you your life. The same applies to webbing though to a far lesser extent. This residual memory is probably the cause of several mid-rope failures both in the real world and during load testing.

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

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

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

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

3c. Knots unsuitable for rescue ropework

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

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

I do not intend to cover every conceivable knot in this book, if you want to learn them all then you could start with the recognised bible, the Ashley Book of Knots. What is important is that you learn which knots to avoid before you start playing with lives.

There are two reasons why a knot is unsuitable – either it has insufficient basic strength or it behaves badly when in use. Many knots are strong enough when dressed and loaded but can fall apart if left slack. Others can capsize into dangerous configurations if loaded in the wrong direction or if trapped against something. This is far worse than a weak knot, as you may decide to rely on this unstable knot for a high-load application and suddenly find it falls apart when you need it most.

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

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

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

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

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

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

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

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

4. 17 essential rescue knots

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

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

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

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

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

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

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

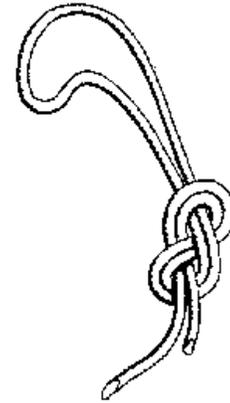
Finally, remember one thing. Knots are the only aspect of rigging for which there exists no standard, no formal approvals and no second chance if you get them wrong.

1. Figure of 8 (F8)

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

Description

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



How to tie

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

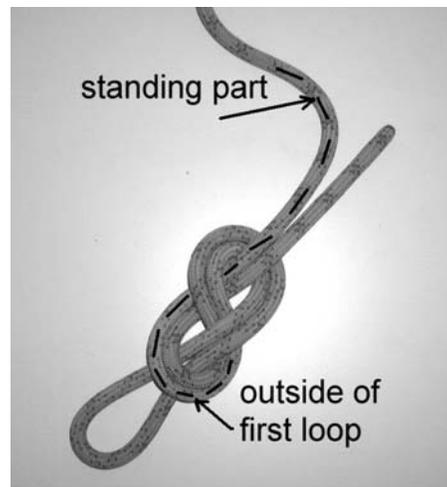


are incorrect. Look carefully at the picture and follow the standing part up into the knot – you can see it appears at the top of the knot, turning *above* the tail end. This is correct. If you get the knot wrong (by making the first twist in the wrong direction) then the standing part appears below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

backwards figure 8 is also far harder to untie after loading – if you get a jammed knot you can bet that it will be the wrong way round.

Applications

Forming a loop in the end of a rope is the obvious application. Always make sure the tail end is at least 50cm long, and tie a stopper knot (a single figure 8) at the end to stop anyone abseiling on the tail. If you tie a figure 8 in a long bight of rope then you get two equal loops and one short tail loop. This has the advantage over the other 2-loop



knots (bowlines) that there is no slipping between the loops, even under extreme tension. A figure 8 on the bight does however use a great deal of length and can be a large and unwieldy knot to tie.

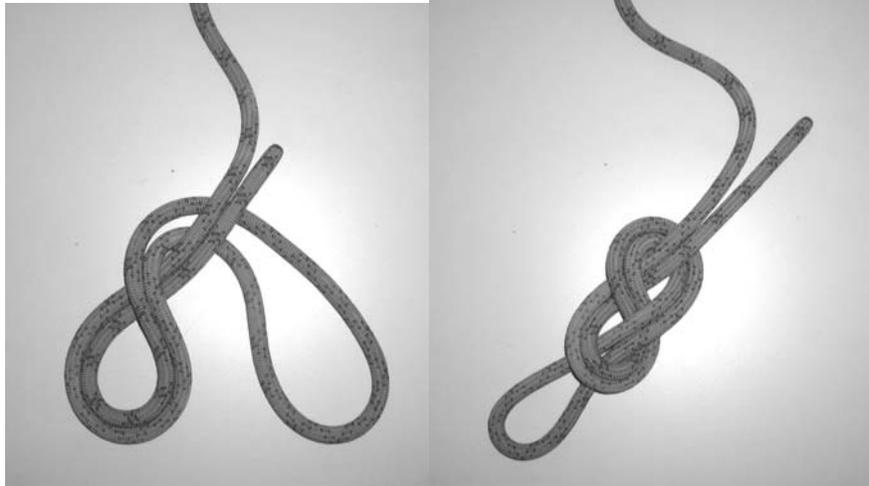
A simple figure 8 at the end of a rope as a stopper knot should always be used in preference to an overhand knot, as the latter can unroll if hit by a high-speed descent. Stopper knots must have at least 30cm of tail and be tied fairly loosely. Some teams use another figure 8 loop knot in the bottom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

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

Potential drawbacks

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

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



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



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



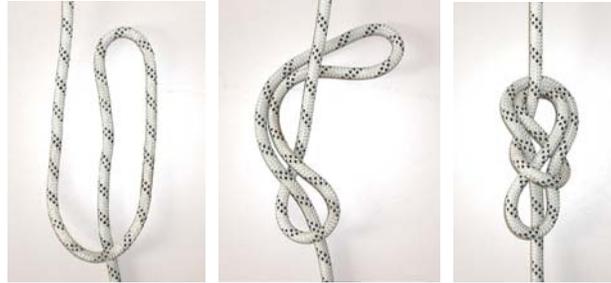
The double figure 8 on the bight (DF8) as shown to the left is simply a normal figure-8 loop knot tied in a long bight of rope. It takes some thought to start the knot as without practice you are tempted to end up with a very long single-loop knot instead! The knot to the left gives two identical loops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

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

It is also possible to create a mid-rope knot from the figure of 8 family, and this is common with US rescue teams, where it tends to be called a ‘directional figure 8’. The

knot has not been so extensively tested as the other F8-derivatives but I will include it here as personally I do think it has benefits, particularly for anchors and belays.

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



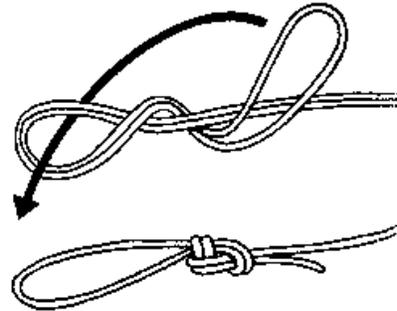
See also: Figure 9, Bowlines, Double-fisherman & Alpine butterfly

2. Figure 9 knot (F9)

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

Description

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



How to tie

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

Applications

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

Potential drawbacks

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

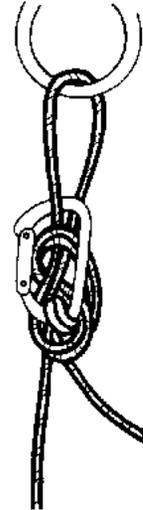
See also: Knots listed with figure 8

3. Stein knot (ST)

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

Description

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



How to tie

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

Applications

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

Potential drawbacks

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

See also: Figure 8, Figure 9 and Bowlines

4. Yosemite Mountaineering Bowline (YMB)

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

Description

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



How to tie

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

Applications

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

Potential drawbacks

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

See also: Figure 8/9 and Stein knot

5. Bowline on the bight (BOB)

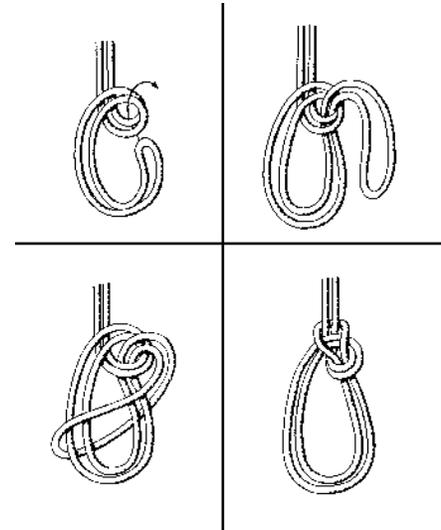
Knot group:	Loop-forming	Breaking strength	60 %
Length lost	40cm	Ease of release:	good
		Suitable material:	Rope ☺ Web ☹

Description

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

How to tie

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



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

Applications

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

Potential drawbacks

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

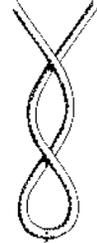
See also: Figure 8, Figure 9, Yosemite mountaineering bowline

6. 'Alpine' butterfly knot (ABK)

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

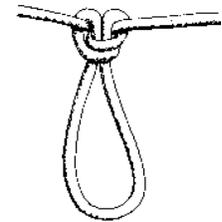
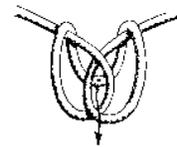
Description

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



How to tie

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



Applications

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

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

Potential drawbacks

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

See also: Figure 8, Figure 9 & clove hitch

7. Italian hitch (HMS)

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

Description

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



How to tie

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

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

Applications

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

Locking off

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

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

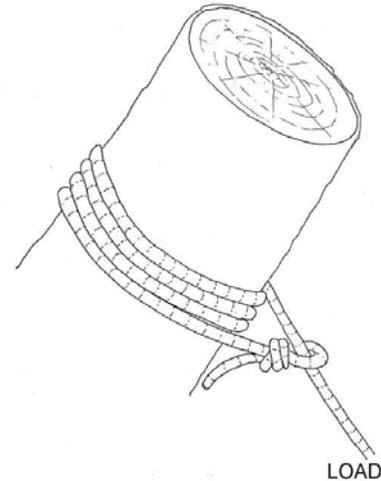
An important and somewhat obvious point needs to be made regarding the use of the HMS for belaying. We have ruled out such use for rescue loads (200kg), though the knot is widely used for belaying a single body (e.g. while ladder climbing). Using the HMS for personal team member belaying is a decision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

8. Tensionless hitch (TH)

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

Description

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



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

How to tie

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

Applications

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

Potential drawbacks

Once tied, taking in rope to adjust the knot is very slow and painstaking. A TH is only as strong as the object it is tied to. The short 'tensionless' tail should not be used for anything loadbearing. When tying in rope or web, make sure the wraps do not overlap each other. The knot assumes that the line of pull is almost perpendicular to the object

(i.e. parallel to the wraps) and of course it is vital that the object is not free to rotate. A final and obvious point is that a rope is only as strong as the weakest knot, so if you apply a TH at the tope of your rope and a bowline at the bottom, don't expect to be able to load your rope to 100% ☺

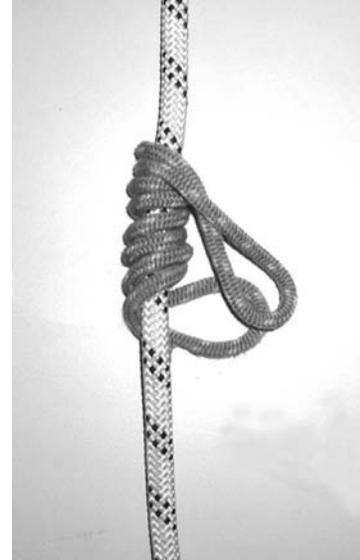
See also: Dog & tails, stein knot and mechanical belaying devices in section 5h.

9. French prusik (FP)

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

Description

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



How to tie

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

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

Applications

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

Potential drawbacks

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

See also: Klemheist, dog & tails

10. Klemheist knot (KL)

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

Description

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

How to tie

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

Applications

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

Potential drawbacks

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

See also: French prusik, dog & tails

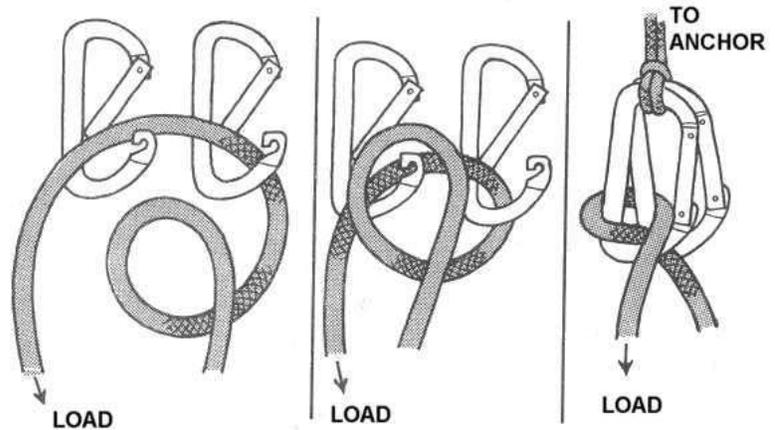


11. GARDA self-locking hitch

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

Description

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



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

How to tie

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

Applications

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

Potential drawbacks

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

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

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

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

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

12. Tape knot (TK)

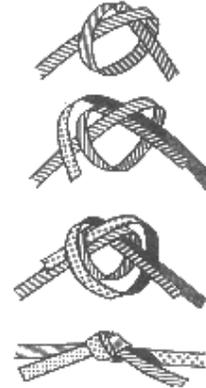
Knot group:	End-joining	Breaking strength	55 – 65 %
Length lost	4x tape width	Ease of release:	poor
		Suitable material:	Rope ☹ Web ☺

Description

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

How to tie

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



Applications

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

Potential drawbacks

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

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

13. Double fishermans knot (DF)

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

Description

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

How to tie

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

Applications

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

Potential drawbacks

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

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

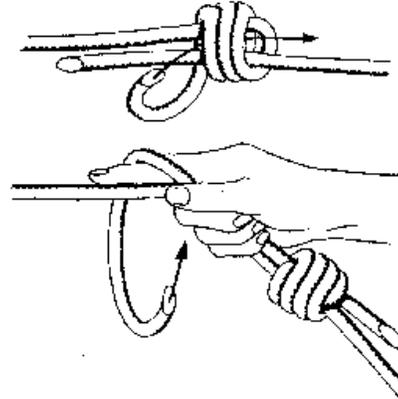


14. Triple fishermans knot (TF)

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

Description

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



How to tie

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



Applications

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

Potential drawbacks

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

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

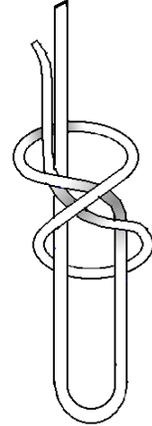
See also: Figure 8/9, double fishermans, barrel knot

15. Barrel knot (BK)

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

Description

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



How to tie

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

Applications

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



Potential drawbacks

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

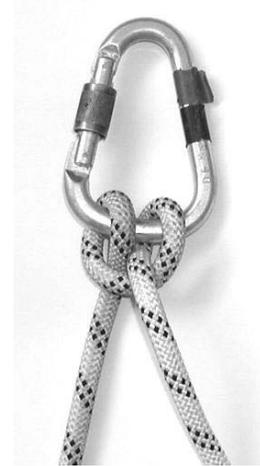
See also: Figure 8/9, double fishermans knot

16. Clove hitch (CH)

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

Description

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



How to tie

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

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

Applications

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

Potential drawbacks

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

See also: Alpine butterfly, tensionless hitch

17. Dog & tails (DT)

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

Description

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

How to tie

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



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

Applications

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

Potential drawbacks

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

See also: French prusik, tensionless hitch, klemheist

5. Anchors and belays

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

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

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

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

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

5a. Loads on anchors during hauls and falls

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

dynamometers to measure the loads during typical ropework operations. The Lyon tests used a normal load, but the TRM belaying tests used a 200kg rescue load.

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

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

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

Climbers use fall protection, because they expect to fall – it’s part of the fun.

Cavers use fall prevention, because they don’t want to fall, it’s not part of the fun.

Casualties use fall prohibition, because if they fall they’ll die. Nobody’s idea of fun.

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

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

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

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

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

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

5b. Natural or found anchors

Underground this usually refers to suitable rock shapes (pinnacles, holes etc) that can provide an anchor by looping or threading a webbing sling. On the surface 'natural' includes anything that is not intentionally moved into position.

In mined passages often 'natural' placements can be found even though they are man-made, hence the occasional use of the phrase 'found' to refer to non-geological anchors. Examples include shot-holes that pass through a portion of rock and re-emerge into the passage, in-situ structural steelwork or heavy objects such as winches, pumps or trains.

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

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

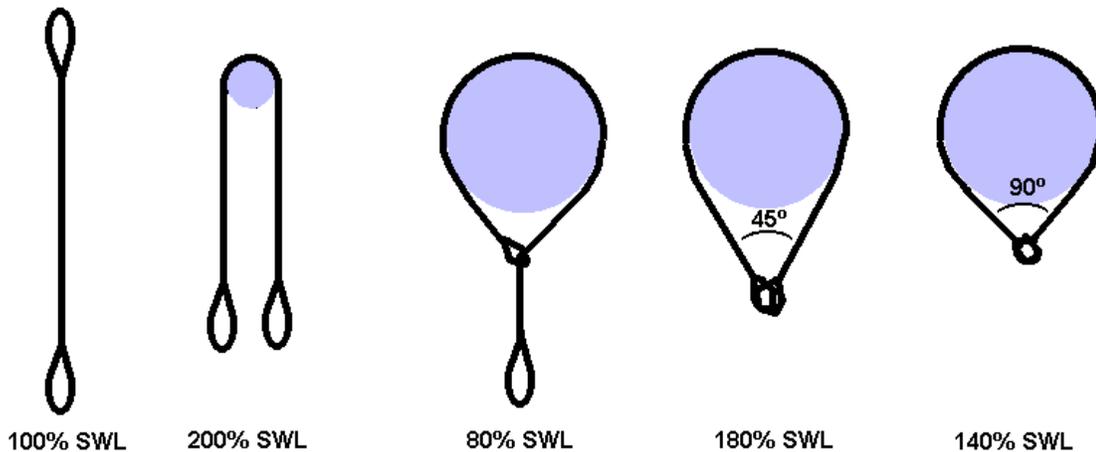
In mines the rigger is faced with the fact that every rock surface available is the result of blasting. Shockwaves can introduce microfissures in rock so that a seemingly-solid face may peel away in sheets when loaded. Of specific concern is the effect called ‘plating’ where a drilled bolt can pull away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

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

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

over it. Canvas or old carpet is fine, rubberised material or plastic sheeting is not. Once a rope has had melted rubber smeared along the sheath it is destined for the bin.

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



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

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

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

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

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

5c. Props

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

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

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

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

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

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

5d. Rock bolts and hangers

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

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

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

Bolts used in rescue are an area of some debate and controversy. Some modern bolts are perfectly suitable to the large rescue loads, other (and older) models are certainly not. The UK programme of resin P-hanger installation undertaken by the CNCC/NCA is in part an attempt to address this. If a rescue rigger is faced with a pitch where P-hangers are in place then for all reasonable situations they can be assumed adequate. Clearly if there are none in place then

there is no possibility of fitting them, as the resin takes up to 12 hours to fully cure. The other problem sometimes faced is that rescue rigging requires different (and more) anchor points than sport caving. An SRT pitch may have only two hangers at the head for sport rigging, but a dual-rope hauling system will require at least 4 at the pitch head and a further 4 some distance back. It is vital that a rigger does not apply multiple loading to anchors simply from lack of options. There is always an alternative (props, drilled bolts etc.). Luckily in many cases the installation of resin hangers has allowed for rescue, fitting additional hangers where needed.

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

Self-drill and pre-drill M8 sleeves

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

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

The concrete issue is quite a problem. '50MPa' refers to the modulus of rupture, in essence the ability of the rock to resist breaking apart under stress. It is measured by trying to break a rectangular beam of rock by bending it in a 3-point load rig, and the lower the figure the more likely a sample is to break apart under load. For expansion anchors the usual route of failure is that the rock 'plates' – a conical section of rock splits away, centred on the anchor. This would

not be too much of an issue if it were not for the fact that concrete has a rather high modulus of rupture due to the aggregate nature of its composition. Limestone, on the other hand, is quite poor. Typical MOR figures for plain white limestone, provided by stone quarries in the UK, vary from 5.5MPa to 15MPa, with some values halving when the rock is very wet.

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

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

Other options

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

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

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

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

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

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

+ These hangers are not supplied with a bolt or expansion sleeve.

++ The SPIT sleeves are typical of those used by cavers. Strength figures are for 23MPa concrete, as these anchors are not designed for use in limestone. Note the very low strength figures!

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

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

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

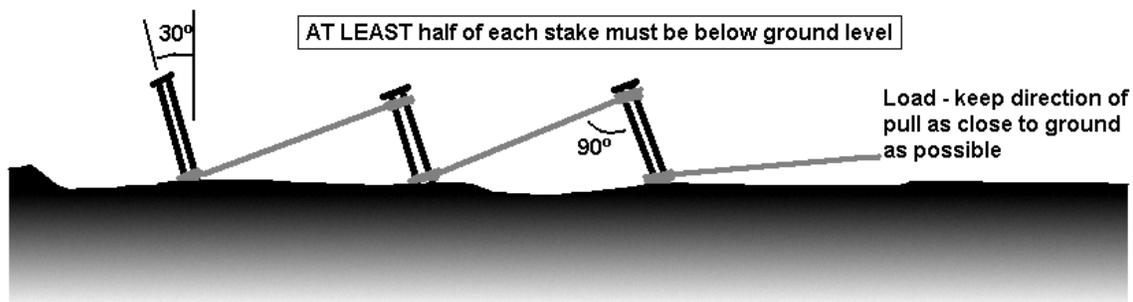
NOTE: Under EN795 it is a requirement that all rock anchors be produced from stainless steel. For this reason all steel plated or alloy hangers, sleeves and studs cannot be CE marked.

5e. Ground belays, stakes and anything else

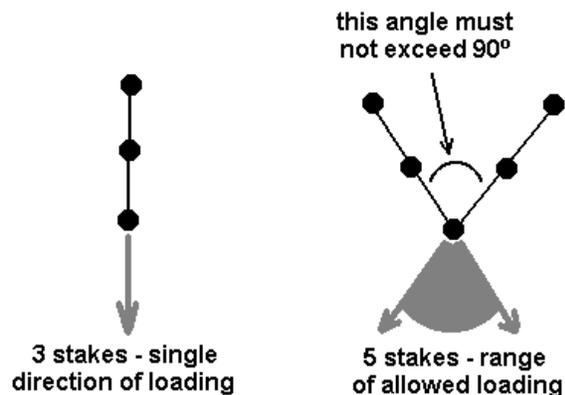
The notion of ground anchors in a cave may seem pointless, but your casualty must eventually make it to the surface, and teams are often asked to work on ‘surface’ incidents such as quarry faces where the great outdoors is your belay. If a landrover is to hand, it can make a very good anchor provided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

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

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



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



5f. Rigging onto anchors

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

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

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

Addressing these in turn:

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

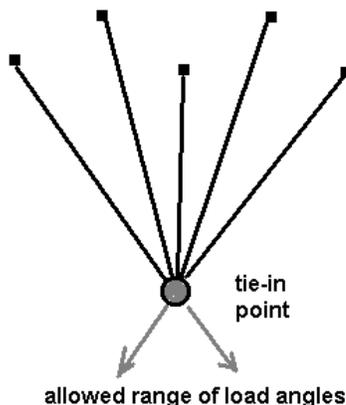
seen as such is the idea of using two anchors and two Y-hangs, as shown below. The same rules apply on using this method.

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

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

5f1. Anchor vectoring

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

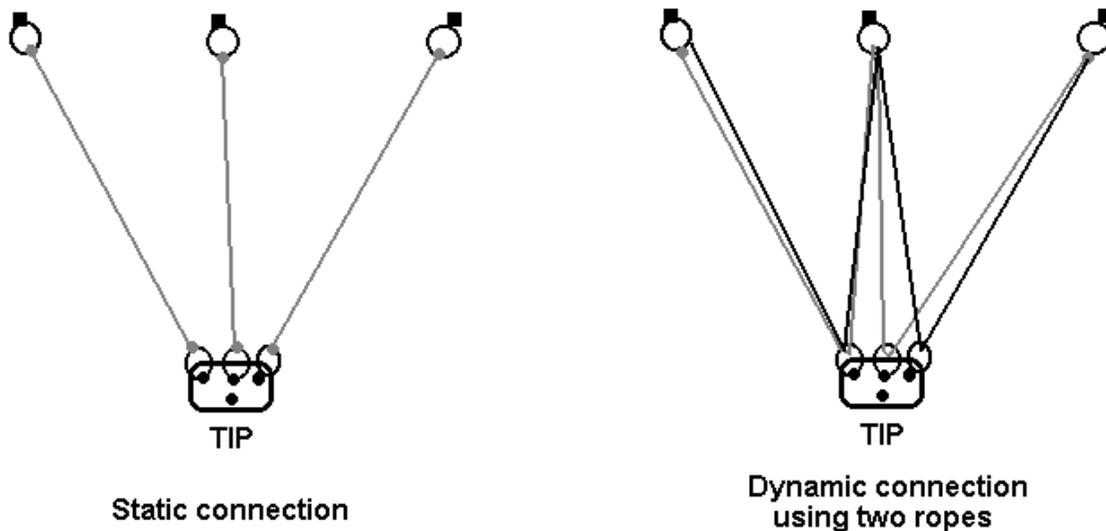


When you are faced with a set of anchors and a need for one tie-in point, there are two ways to go about interconnecting everything. The static approach says that you secure a fixed sling or rope from each anchor to the TIP, bringing them all together at a plate or collection of krabs. The length of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

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

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

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



5g. Belays for rescue

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

Section 7b discusses the use of backups and safety lines in detail, here we are addressing the belaying devices themselves. For now we will accept the simple premise from 7b that any live load (a person) that could suffer injury should one item of equipment fail must have a safety line and belay. In rescue this applies to almost all ropework, in sport caving it is most

commonly seen as the safety line for a ladder-climber. Sport cavers using SRT dispense with the safety line, though industrial access workers retain it.

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

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

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

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

5h. Belaying equipment

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

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

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

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

Rope types

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

Manual methods

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

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

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

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

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

Automatic devices

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

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

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

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

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

*The Stop passed with 11mm dynamic rope, peak load 6.6kN and 25cm slippage.

** 8mm static cord, 3 wraps, classic prusik knot and 10cm spacing between each knot.

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

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

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

5i. Releasable belays

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

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

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

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

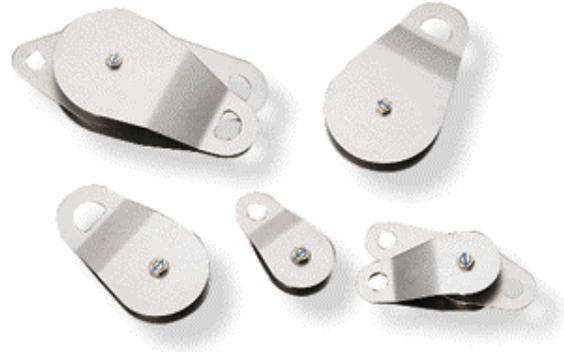
Using a tied-off friction knot such as an Italian hitch is the other option – but remember that these knots are difficult to pay out when under a 200kg load. One way around this is to take several turns of the rope from the anchor to the STIP and back again, making a big compound pulley block before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

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

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

6. Pulleys

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



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

6a. Types of pulley

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



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



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

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



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



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

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



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

6b. Choosing pulleys for rescue

Choosing between models is a matter of cost and availability as well as strength. However at this point I must make an important statement about the rule on strength and the exceptions to the rule. For common rescue applications of deviating a rope then pulleys must be rated at full rescue loading as we shall describe below. However for the **specific application of an A-block** as discussed in Section 8a, pulleys of lower strength can be used. This is contradictory to the

general rules on not including weaker components in rescue kits, however in the case of the A-block there is a valid reason. Inclusion of a rope clamp into the A-block results in a very low working strength, defined by the teeth of the clamp. Typically this is only 4kN, therefore it can be argued that a pulley need not be rated to a significantly greater strength. We will discuss this in detail in Section 8a, however it is this reason that allows us to include the Petzl Fixe pulley in our approved lists. This pulley is not rated for a full rescue load, however is specifically designed for making A-blocks and is it difficult to find a better alternative.

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

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

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

6b1. General pulleys for a full rescue load

For rescue hauling a minimum working strength per side of 15kN is essential (thus a rated strength of the mounting point of 30kN). Most rescue pulleys provide this with ease, though some are stronger than others. The Petzl P50 is rated at 16+16kN, whereas the Kong Heavy Duty is rated at 25+25kN. As well as strength, pulleys used in rescue must be compatible with the ropes used (i.e. have a maximum capacity greater than 11mm) and should offer good points of attachment. The use of double-sheave or becketed pulleys is a matter of rigging, though in UK cave rescue neither are vital and their inclusion in kits is a team decision.

As we shall see when constructing hauling systems, it is often important to connect more than one karabiner into the pulley. Some rescue pulleys, such as the SMC models, have holes only large enough for one krab, and so is not an advisable part of the kit when multiple-capacity pulleys of the same strength and price are available.

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

6c. Minder slings

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

The simplest solution is to install a ‘minder sling’ – simply a karabiner clipped into the line on one side of the pulley and attached by a sling or dynamic rope loop to a pair of anchors. Ideally these should be separate from those supporting the pulley, but caves are never ideal. Even using

the same anchors you will protect against pulley failure itself. Of prime importance is that the possible fall factor is minimised – so the sling should be as short as possible whilst not coming under direct tension.

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

6d. Pulley mechanics

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

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

A 60° bend will create a force on the pulley anchor of F

A 90° bend will create a force on the pulley anchor of $1.4F$

A 180° bend will create a force on the pulley anchor of $2F$

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

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

6e. Dynamic friction and edge effects

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

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

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

All pulleys, devices and edges have a friction factor (which I will denote β to avoid confusion with fall factor). This is the ratio of forces in the two sides of the rope when the rope is moving, and is a measure of the friction. The value of β depends on many factors and is difficult to predict with accuracy, but the most important influences are the object itself and the angle through which the rope deviates. A larger angle means that (in general) more of the rope is in contact with the object and so the friction is higher. For pulleys however this does not apply, as the rope itself does not move with respect to the sheave. The contact between the sheave and bearing is fixed, so **the value of β for a pulley is constant with deviation angle**. Of course other factors such as mud, water or extremes of temperature can change β dramatically.

For rescue pulleys having a value of $\beta < 1.3$ then the effects can be neglected in common rigging. All other devices with $\beta > 1.3$ must be thought through carefully as a rigging system is being installed, or you may find the forces on anchors or karabiners escalate to the failure point very quickly!

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

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

* Fixed so as not to rotate as the rope moves.

⁺ Rope is being raised, therefore pulling through these devices in the non-locking direction.

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

6f. Peak forces

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

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

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

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

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

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

$$\text{peak load} = 1000 \times 1.1 \times 1.5 = 1650\text{N}$$

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

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

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

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

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

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

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

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