Department of the Interior
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EMERGENCY SERVICES

TECHNICAL RESCUE HANDBOOK

12th Edition

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NATIONAL PARK SERVICE
TECHNICAL RESCUE HANDBOOK

Twelfth Edition. February 2023

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Former editions written and illustrated by Ken Phillips. The twelfth edition was updated by the NPS National SAR Working Group, editor Brian Hays. Additional contributors: Jason Ramsdell, Sara Robinson, Nick Armitage, Kevin Moses, Jesse McGahey, Kevin Sturmer, James Thompson, and Justin Spain.

All images, unless otherwise noted, are credited National Park Service. Every effort has been made to utilize images which reflect the most technically accurate procedures, however like the real world, achieving perfection is elusive and slight inaccuracies may still be observed.

WARNING

Technical rescue involves unique hazards, which can be fatal. This textbook contains information on specialized rescue techniques and is intended for use as a part of a training course involving closely supervised field training with qualified instructors. A person cannot become proficient in technical rope rescue by simply reading this handbook. Every rescue situation is unique, requiring size up and decision making skills gained through personal experience.

Cover Photo: The NPS rescue team at Arches and Canyonlands National Parks conducts a technical lowering operation. Photo by Jason Ramsdell.

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PREFACE

This handbook is intended to provide a comprehensive instruction manual as well as point of reference for National Park Service (NPS) personnel involved in technical rope rescue. The techniques provided in the text reflect the consensus of best practices for use within the NPS as established by subject-matter experts both internally and outside the agency.

This text has evolved from a few pages originally used as class handouts for the NPS Basic Technical Rescue Training Course starting in 1995. Rope rescue, like other emergency disciplines, constantly changes with advances in equipment designs, field testing and lessons learned from accidents. Many practices that were dogma in technical rescue have been invalidated through analysis and testing.

Maintaining perishable personal rigging skills associated with rope rescue requires recurrent training. Manipulative drills will directly increase personal proficiency and improve organizational readiness. Rescuers need to stay current with accepted industry practices. It is critical that commercial rescue equipment be employed in a manner that complies with the manufacturer's operating instructions.

In the rush to respond, rescue personnel repeatedly and intentionally take shortcuts with their personal safety. This human error is the leading cause of accidents.

- Always drive with due care when responding to an emergency.
- Constantly use all your personal protective equipment, including helmet, gloves and eye protection.
- Be disciplined about tying in to a safety line when working where the potential for a fall exists.
- Avoid a back injury, which is the most common SAR-related injury, by getting additional assistance with heavy loads.

Finally, truly recognize the associated risk with technical rescue operations and make effective decisions to reduce or eliminate risk. Strive to learn from any operational shortcomings and continue to seek out new information.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 NPS TECHNICAL RESCUE — HISTORICAL BACKGROUND

Figure 1.1-1 LEFT: 1967 rescue on the North Face of the Grand Teton (photo Rick Reese). RIGHT: 1972 rescue on El Capitan (photo Gary Hathaway NPS).

National Park Service rangers conduct technical rescues in some of the most iconic and challenging vertical terrain on earth. This handbook presents both specific rescue techniques and big picture lessons learned by rangers over many decades and thousands of rescues. The 12th edition draws from the knowledge and experience of rangers across the Service, leading rope rescue training professionals, and information presented in previous editions.

The first service-wide National Park Service "Mountain Climbing and Rescue Training School" was conducted September 13, 1948, at Mount Rainier National Park. "The five-day program included practical instruction in knot-tying and roped party management, proper use of rock and ice climbing equipment, belays, rappels, self and party arrests, crevasse rescue of all types, tying-in of stretcher cases[1], improvisation of stretchers, belaying stretcher cases (in ascent, descent and traverse), construction of Tyrolean traverses with A-frames, and rope bridges…It is hoped that the extreme

[1] Today we refer to "stretcher cases" as "rescue litters."

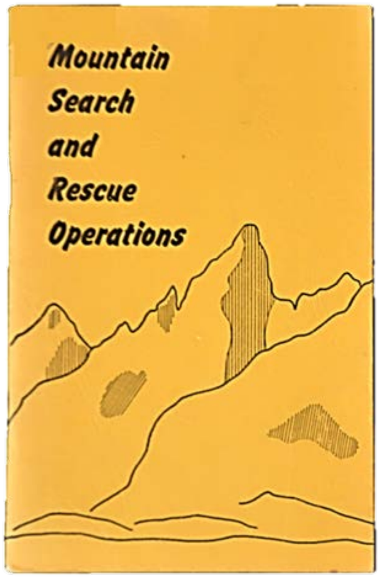

Figure 1.1-2 Mountain Search and Rescue Operations

enthusiasm and cooperation which were in evidence during the school may be indicative of the efficiency with which future mountaineering activities and rescue operations will be conducted."[2]

Several NPS rangers involved with the initial development of the NPS Mountain Rescue Program gained valuable experience in the Army 10th Mountain Division at Camp Hale (CO). This included Fred "Doug" McLaren, who left the Army in 1946 and joined the NPS. Later as a Supervisory Ranger at Grand Teton in 1958 McLaren, with the assistance of rangers John Fonda and Richard Emerson, prepared the first comprehensive NPS SAR Manual titled "Mountain Search and Rescue Operations" (Figure 1.1-2). This text provided instruction on accepted rescue techniques for the NPS at the time.

Joshua Tree National Park held its first formal technical rescue training program in January 1981. The week-long training attracted increasing numbers of rangers from other parks, eventually becoming the default national training. The course was taught by American Rescue Institute at Joshua tree in 1990-1992. It then moved to City of Rocks in 1993, and finally to Canyonlands in 1995. That year two standardized training courses were instituted; a western course at Canyonlands National Park, and an eastern course held first at New River Gorge. The courses have been an integral part of the NPS technical rescue program and have continued, mostly uninterrupted, to the present day.

As rescue techniques evolve so does course curriculum. This handbook serves as a companion to the NPS Basic Technical Rescue Course or your equivalent in-park training program.

1.2 INTRODUCTION TO RESCUE OPERATIONS

One way to conceptualize the phases of a rescue operation is the LAST acronym: Locate, Access, Stabilize, Transport. Additionally, teams may use the following recommendations to maintain an orderly response:

1. Immediately and clearly establish an incident commander.
2. "Size up" and verify the initial report by questioning the reporting party (RP):
    1. Precise location and terrain type
    2. Number of subjects
    3. Subject condition / injuries
    4. Hazards

[2] American Alpine Club. United States, Mountaineering in the National Parks.

3. Send a hasty team to get eyes on scene. Locate, Access, and Stabilize the subject (EMS care).
4. Organize resources and assign roles in an ICS structure.
5. Transport the subject to safety and/or definitive medical care.
6. Conduct law enforcement investigation if warranted.
7. Conduct a hot debrief of the operation.
8. Perform critical incident stress management (CISM) and/or peer support as needed.
9. Conduct an after action review (AAR) as needed.
10. Complete incident documentation and paperwork.

The National Incident Management System (NIMS) directs responders to utilize the Incident Command System (ICS) to manage all emergency incidents across local, state, and federal agencies. Utilizing ICS greatly improves organization, especially during the challenging initial phases of the operation. Important principles of ICS applicable to technical rescue include: clearly designate who is in command, delegate and assign ICS roles, expand and contract the ICS structure as necessary, and maintain an appropriate span of control.

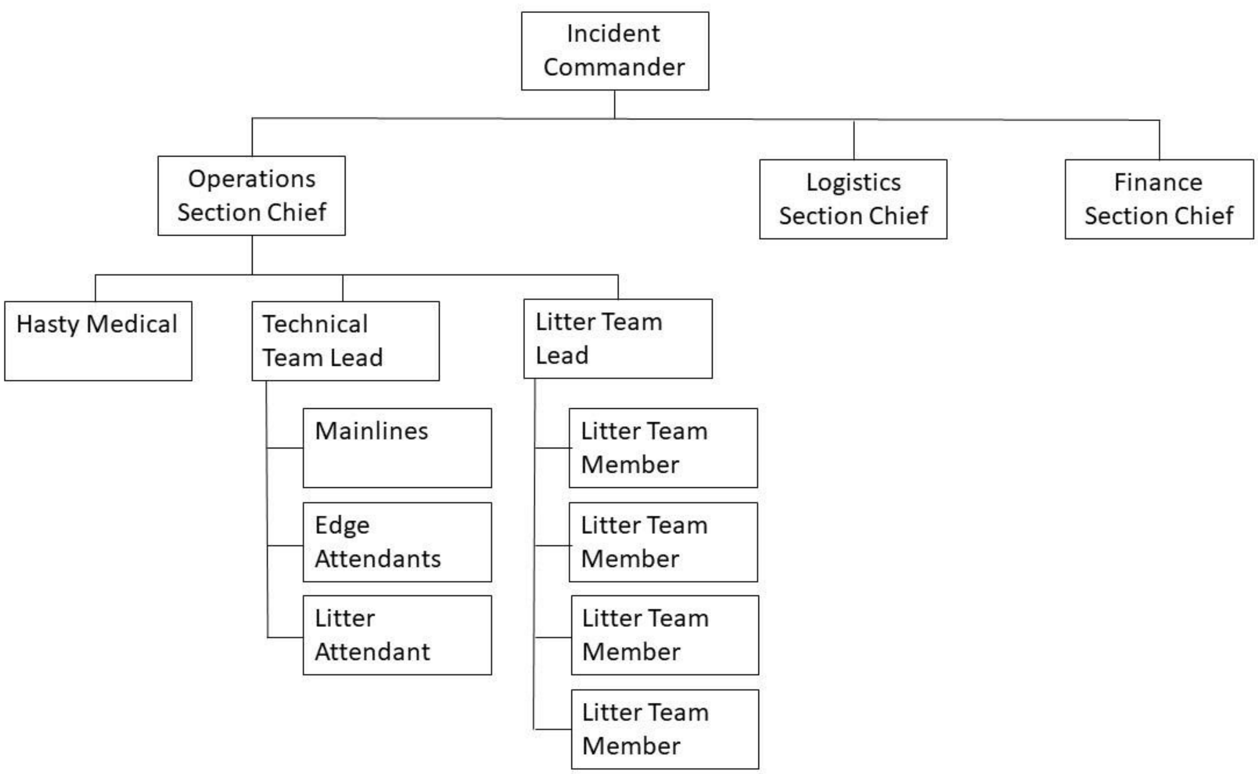

Figure 1.2-1 Common ICS structure for a technical rescue incident

1.3 INTRODUCTION TO TECHNICAL SAR

For the purposes of this handbook “technical rescue” refers to rescues utilizing rope systems to access and move injured or stranded subjects from high angle or steep angle terrain to safety.

Technical rescues account for ten percent or less of all SAR incidents; however, these rescues are often the most complex, the most hazardous, and the most time consuming of all SAR operations. For these reasons we spend a disproportionate amount of time training for technical rescue. It is critical that rescuers continue to refresh, gain experience, and train on these skills.

The ability to professionally execute a technical rescue depends upon many factors above and beyond the rigging skills of rescuers. Teams must be fluent with the Incident Command System. Personnel must be familiar with, and skilled at traveling through, the technical terrain in their park. Equipment must be organized and response ready. Rescuers need to be trained and equipped to provide emergency medical care. Communications systems must be robust. Much of this preparatory work should be identified and prepared through a park SAR needs assessment and SAR plan long before responding to a call for help.

Figure 1.3.1-3 Rescue Equipment 1) Yosemite National Park SAR Rescue Three is a dedicated rescue truck providing mobility of equipment. 2) Rocky Mountain National Park Boulderfield Cache is a secure storage container situated below Longs Peak to aid in area responses. 3) Pre-rigged equipment modules increase response readiness.

1.4 EVOLUTION OF NPS TECHNICAL RESCUE SYSTEMS

There has always been variation in the equipment and techniques used by different NPS technical rescue teams. In recent years, those differences have evolved and branched out more than ever before. This differentiation is beneficial to the degree teams optimize techniques to their operating environment. It also makes writing a one-size-fits-all handbook a challenge.

This handbook will present one good way to rig technical rescue systems. It is recognized there are numerous other “right” ways of doing business. General principles and techniques will be presented in the following pages which the competent rescuer can critically evaluate then apply to suit their local operating environment.

2. SAFETY

2.1 TECHNICAL RESCUE SAFETY

SAFETY IS THE NUMBER ONE CONSIDERATION. As members of a rescue team, we are responsible for the safety of team members, the person being rescued, and bystanders. In training we vigorously practice good safety habits, so they become automatic on real incidents. Safety is everyone's responsibility. Remember to "lead by example," especially around students or beginners. In keeping with this spirit, the following safety rules should be followed in training and on real incidents:

- GET A SAFETY INSPECTION. Before operating your station or crossing the safety line, get a safety inspection. Ask for someone different to check your work regarding all rigging and systems. In a training environment, ask your instructors if you are qualified and approved to do an inspection. You must be sure you understand standards and are qualified to check the system. On some large incidents a specific Safety Officer may be assigned, but efficiency and safety increases if everyone is a safety officer for each other.

- TAKE PERSONAL RESPONSIBILITY. Carry gear to keep yourself warm, dry, and fed on extended operations. Drink lots of water, use sunscreen, and beware of fatigue. Don't go beyond your technical skill level. Speak up if you are assigned a task you don't feel qualified for. Ask questions if you are unclear on instructions. Check on your fellow team members.

- USE PERSONAL PROTECTIVE EQUIPMENT. This includes helmet, harness, gloves, clothing, eye protection, headlamp, etc.

- NO HORSEPLAY. Act professionally — you represent your park and/or agency during operations and training. When a rescue operation is in progress, keep chit chat to a minimum to reduce distractions and so communications can be heard by the team.

- AVOID COMPLACENCY. Rotate positions, stay engaged, fight boredom and laziness, attempt to learn and improve your technique, don't assume, and don't blow off the basics of buddy and/or safety checks. Human error is the biggest risk on any technical rescue operation.

- ANYONE CAN YELL "STOP!" if they observe a safety concern. However, only the team leader can say "go".

- DOUBLE CHECK THAT YOU ARE TIED IN when working near the edge or anytime you're in an exposed area where falling off would cause injury or death. Establish a marked safety perimeter. Minimize the number of personnel working near an edge.

- RESCUE SYSTEMS SHOULD BE REDUNDANT. Double check everything. Analyze the system and verify there is no potential for catastrophic failure if any one component fails. Re-check ropes and equipment continually. Pad sharp edges. Belays will be used on all rappel and ascending operations during training.

- PRE-CLEAN AND SECURE THE EDGE BEFORE THE OPERATION. Be extremely careful about sharp edges, loose debris and equipment near edges. Aggressively pad the edge. Ropes that easily hold 30 kN can be cut at much lower forces on a sharp edge. Yell "ROCK!" if anything is dropped. Secure loose gear in a cache adjacent to the rescue operations area. Keep the operational area neat and organized.

- NEVER GET ON A ROPE WITHOUT A WAY TO GO UP <u>AND</u> DOWN THE ROPE. Remember to carry a Prusik and trauma scissors or rescue knife with you. Are you prepared to do a self-rescue if you get stuck?

- INCORPORATE THE PRINCIPLES OF OPERATIONAL LEADERSHIP. Accept no unnecessary risks. Use GAR/SPE and other risk analysis tools during training and live missions. Encourage group participation and discussion in risk analysis. The GAR process should focus on discussion and mitigations not just the actual score. Focus on personal and team situational awareness.

- EXPECT DIFFERENT STYLES AND TECHNIQUES. During SAR training or live missions, you may have different techniques shown to you. There are many ways to complete a task safely. Learn the difference between a “show-stopper” which violates safety principles, and just different “styles”.

2.2 SAFETY INSPECTIONS

Safety inspections are critical to operational safety. There are several basic concepts for inspections to be effective on any type of technical rescue: 1) Independent: you cannot inspect your own work. 2) Visual and tactile “tug test”. 3) Methodical: systematically checking each link in the chain. Also, if any changes are made to the system after the inspection, then that component should be inspected again. Other than training situations, it is assumed that competent rescuers on a team can perform safety inspections for any component of the system. The goal is to keep the operation running efficiently and timely, while being safe. Differences in style from one rescuer to the other should be allowed if it does not violate standards and/or safety norms.

2.3 OPERATIONAL RISK MANAGEMENT (ORM)

As an operation progresses and evolves, personnel should continuously employ the following key principles of operational leadership:

1. Accept No Unnecessary Risk: SAR operations entail risk. Unnecessary risk conveys no commensurate benefit to safety of a mission. The most logical courses of action for accomplishing a mission are those meeting all mission requirements while exposing personnel and resources to the lowest possible risk.

2. Accept Necessary Risk When Benefits Outweigh Costs: The process of weighing risks against opportunities and benefits helps to maximize unit capability. Even high-risk endeavors may be undertaken when decision-makers clearly acknowledge the sum of the benefits exceeds the sum of the costs.

3. Make Risk Decisions at the Appropriate Level: The appropriate level to make risk decisions is that which most effectively allocates resources to reduce the risk, eliminate the hazard, and implement controls. Incident personnel must ensure subordinates are aware of their own limitations and when to refer a decision to a higher level.

4. Integrate ORM into Operations and Planning at All Levels: While Operational Leadership is critically important in an operation's planning stages, risk can change dramatically during an actual mission. Incident personnel should remain flexible and integrate Operational Leadership in the planning and execution phases.

2.4 GAR RISK ASSESSMENT TOOL

One effective operational leadership tool is the GAR (Green-Amber-Red) risk assessment model; a GO/NO-GO, decision tool. The mitigation of risk and safe completion of the operation is the goal of any risk assessment tool. The GAR model assesses the opinions of multiple involved personnel to generate a risk score.

GAR respondents independently assign a personal risk score to eight different elements associated with a mission. The risk score is **1 (Low Risk)** through **10 (Maximum Risk)**, which is a personal estimate of risk.

The following elements are evaluated:

- **SUPERVISION —** The presence of qualified, accessible and effective supervision on the incident. A clear chain of command is in place.

- **PLANNING**— Adequate incident information is available and clear. There is enough time to plan, operational guidelines are current, briefing of personnel is being conducted and team input is solicited.
- **CONTINGENCY RESOURCES**— Backup resources that can assist if needed. Evaluate shared communications plan and frequencies. Has an alternative plan been evaluated?
- **COMMUNICATION**— Evaluate how well personnel are briefed and communicating. How effective is the communication system and is there is an established communication plan? Does the operational environment value input?
- **TEAM SELECTION**— Team selection should consider the qualifications and experience level of the individuals. Consider the experience for the mission being performed.
- **TEAM FITNESS**— Consider the physical and mental state of the crew. Evaluate team morale, fatigue, and any distractions.
- **ENVIRONMENT**— Consider factors affecting performance of personnel and equipment such as time, temperature, precipitation, topography and altitude. Evaluate site factors such as narrow canyons, forest canopy, technical terrain, snow, swift-water, etc.
- **INCIDENT COMPLEXITY**— Evaluate the severity, exposure time, and probability of a mishap. Assess difficulty of the mission and proficiency of personnel.

The team members should individually complete GAR scores for a planned task without input from others. The individual risk scores are summed to come up with a Total Risk Score. If the total risk score falls in the green zone (8 - 35), then the risk is rated low and the mission is considered a "go." A score in the yellow zone (36 - 60) indicates moderate risk and additional mitigations or controls should be put in place before proceeding with the mission. If the total score falls in the red zone (61 - 80), the risk is significant, and this indicates a "no-go" until the risks can be mitigated further. Upon completion, the team reviews their results together.

GAR RISK ASSESSMENT SCORE		
8 - 35	36 - 60	61- 80
GREEN GO— Proceed With Mission	**AMBER** Caution— Mitigate Hazards Before Proceeding	**RED** NO-GO— Stop! Do Not Proceed With Mission

How to use the GAR Model effectively: The ability to assign numerical scores or color codes in the GAR Model is not the key ingredient with this tool. The key ingredient occurs when team members discuss their scoring results and mitigations to the risk together. **Focus on mitigations to risk in each category regardless of the score,** and pay special attention if scores are drastically different among team members.

This brief introduction to Operational Leadership principles does not replace the need for completion of an Operational Leadership course and other risk management skills.

2.5 SITUATIONAL AWARENESS

Most climbing and rescue related accidents are not a direct result of equipment failure, but instead have "human error" as a primary causal factor. Therefore, we should always engineer and pre-plan for the weakness of the human factor on rescue operations. Remember that individual situational awareness is **hard to maintain, and easy to lose.** Working in a team environment with open communication helps to offset this problem.

Factors that reduce situational awareness include:

- Insufficient communication
- Fatigue/stress
- Task overload
- Group mindset
- "Press on regardless" philosophy
- Degraded operating conditions

Techniques to prevent the loss of situational awareness:

- Actively question and evaluate your mission progress
- Update and revise your image of the mission
- Use appropriate assertive behaviors when necessary:
  - ✓ Make suggestions
  - ✓ Provide relevant information without being asked
  - ✓ Confront ambiguities in assignments
  - ✓ State opinion on decisions and procedures
- Refuse unreasonable requests

2.6 EDGE SAFETY

Establish a marked hazard (exclusion) zone at the edge of a cliff or hazardous drop. This setback distance is a minimum of six feet and is established to prevent an individual from tripping near the edge and being unable to stop themselves. A site with a downward incline, rolling or stair-stepped edge may require that this hazard zone be established much further back. All personnel entering this hazard zone must be secured by a safety line which restricts their travel to the edge of the drop. This can be accomplished with an adjustable prusik on the safety line (Figure 2.6-1). Secure all equipment positioned inside this area (e.g., artificial high directional tripod) with a tether or safety line. Minimize the number of personnel working near an edge, since they have the potential to generate rockfall below.

Be tied in with a safety line when working in an exposed location (within six feet of an edge where a drop of six feet or greater exists). This safety principle is easily violated by personnel focused on the urgency of the mission. Be disciplined and ensure full compliance during an incident.

Figure 2.6-1 Establish a Marked Hazard Zone. Personnel working in this area must be tied in with a safety line which restricts travel to the edge.

Recoil or Snapback Hazard

When a heavily tensioned rope breaks, or an anchor fails, there is a sudden release of energy in the rope that will cause it to recoil back in unpredictable directions with great force. This can result in possible injury to persons in its path. The Cordage Institute warns that "persons should never stand in line with or in the general path of rope under tension to avoid snapback injuries."[3] (Figure 2.6-2)

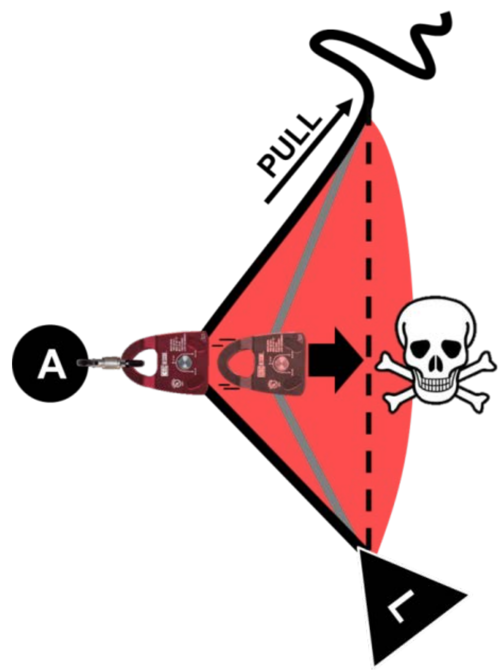

Figure 2.6-2 Don't stand inside a bight of rope under tension! You make yourself a target in the event of equipment failure.

Avoid standing inside a bight of rope (vector zone) under tension, such as inside of a directional.

[3] Cordage Institute. CI-1201. Fiber Ropes- General Standard.

3. COMMUNICATIONS

3.1 OVERVIEW AND MISSION BRIEFING

A mission briefing helps ensure good communication among team members. Optimally this occurs face-to-face. However, geography may require this be done by radio or phone. The following format is recommended:[4]

FORMAT FOR BRIEFING IN EMERGENCIES

1. Here's what I think we face;
2. Here's what I think we should do;
3. Here's why;
4. Here's what to keep our eye on;
5. Now, talk to me.

3.2 USE CLEAR TEXT

It is imperative to communicate in a clear and concise manner. ICS mandates the use of clear text to prevent misunderstandings. Do not use 10 codes or overly technical vocabulary. When referencing directions in the vertical environment, they are often stated from the perspective of a climber facing the cliff; as in "climber's left" or "climber's right".

3.3 KEEP IT BRIEF

Specific words should be used for specific actions. As noted elsewhere, the only word for cessation of action is "Stop!" Do not substitute any other words. "Whoa," for example, could easily be mistaken for "slow," or even worse, "go." For clarity in commands, any team member can say "Stop!" Only the team leader will give the command to proceed. The shortest, cleanest, and clearest commands for moving a litter attendant and patient up or down a cliff are, "Up slow" and "down slow," respectively.

3.4 CLOSE THE LOOP

Rescuers can employ closed loop communication, which is a technique used to avoid misunderstandings. When the sender gives a message, the receiver repeats it back. The sender then confirms the message using the word "affirmative". When the receiver incorrectly repeats the message

[4] Adapted from Karl Weick, South Canyon Revisited; Lessons Learned from High Reliability Organizations

back, the sender will say “negative” and then repeat the correct message until the receiver repeats it correctly, thus closing the loop (Figure 3.4-1).

3.5 BE ASSERTIVE

Team members should immediately speak up with critical information. Never assume. Assuming that someone else on the team sees a hazard may result in a needless tragedy unless somebody speaks up—that somebody needs to be you. If you see something, say something. This level of open communication will not occur naturally. In order to help them overcome the natural, self-imposed psychological pressure to not speak up, team members must be actively encouraged through briefings and an overarching team culture of mutual respect to communicate in critical circumstances.

Figure 3.4.1- Effective communications. Repeating messages back for clarity as well as using direct statements are both effective techniques for critical communications.

3.6 COMMUNICATION: USING DIRECT STATEMENTS

During situations involving critical communication it is most effective to use **direct statements**. Direct statements are difficult to ignore and very effective.

<u>The six components of direct statements include:</u>

1. Use the name of the person you are addressing.
2. Use “I statements”—State "I think," "I believe," or "I feel."
3. State your message as clearly as possible.
4. Use the appropriate emotion for your message so that it is delivered as you intended. Tone of voice speaks volumes, even over the radio.
5. Require a response by using questions such as "What do you think?" or "Do you agree?"
6. Don't let it go. Don't disengage from the other person till an understanding is achieved.

Example: "Jane, I think we need additional personnel for this rescue operation. Do you agree?"

3.7 WHISTLE SIGNALS —“SUDOT”

A standardized signaling pattern that may be employed with a whistle or other audible device, such as a compressed air horn or vehicle horn, provides a non-electronic alternative for communication. This system, known as SUDOT, is a recognized whistle command system used in rope rescue:

COMMAND	WHISTLE BLASTS	MEANING
Stop	One long blast	Stop all movement until further instructions provided
Up	Two short blasts	Movement of the load upward
Down	Three short blasts	Movement of the load downward
Off Rope/Rope Free	Four short blasts	Rescuer clear of the rope and it is available
Trouble/HELP!	Continuous blast	General emergency call

Reference: ASTM Standard F1768- Standard Guide for Using Whistles During Rope Rescue Operations.

3.8 HOT DEBRIEF

At the conclusion of a rescue operation a hot debrief should be conducted. The overall goal of any incident review is to improve future response, which prevents repeating known deficiencies and operational shortcomings. Conducting an informal "hot debrief" immediately at the conclusion of the incident effectively captures feedback from all involved personnel while the incident is still fresh on everyone's minds.

The strength of immediacy in conducting the review is that personnel are actually more receptive to discussing any flaws in the operation right on the heels of its conclusion. With the passage of time personnel develop mental justifications for less than optimal performance and are less receptive to critical discussions.

AFTER ACTION REVIEW —"HOT DEBRIEF"

- What Was Planned?
- What Actually Happened?
- Why Did It Happen?
- What Can We Do Next Time?

During the debrief, focus on WHAT, not WHO. When an operational deficiency is recognized, rather than publicly blaming a person for it, attempt to identify the specific root cause so that appropriate corrective action can be implemented. Investigate each problem at the source and ask 'why' about *every* problem.

It is often challenging to articulate WHAT happened or WHY it happened without somehow connecting it to WHO was directly involved. After all, there are a lot of moving parts at a technical rescue scene, and most of them are human. Do not place blame in the debrief. It is okay, and even healthy, for a person to identify his or her observations about his or her OWN errors. By doing this, a person can highlight an area where some improvement can be made, identify possible training needs in the future, and maybe even set the example for other team members to voice their observations about something they feel they could have done better. This type of discussion has the potential to lead to safer operations and a healthier team culture without the tension and stress that can result when team members blame OTHERS for errors.

3.9 AFTER—ACTION REVIEW

Reviews of large-scale incidents, particularly those involving numerous agencies, can be better managed through a more formal after-action review (AAR), which should be scheduled within a few days of the incident.

Considerations for a successful AAR:

- Extend invitations to representatives from all involved agencies.
- From the above agencies, what positions should be present at the AAR? For example, should agency administrators, unit safety officers, division chiefs, etc., be invited? Does the home unit have a policy or SOP that addresses this?
- Utilize a comfortable location without distractions.
- Employ a neutral facilitator for a very large AAR.
- Establish the ground rules; encourage candor and openness. This is not a critique. It is an open and honest, professional discussion.
- Adhere to a posted agenda format that provides structure on what will be covered.
- Identify best practices.
- Address operational deficiencies.
- Capture action items for future improvement and who will address it with deadlines.
- Document the discussion points and distribute to the involved agencies.

After-Action Action Review Format:

- Was It Safe?
- Was It Effective?
- Was It Efficient?

During the AAR review the following factors:

- Policy and procedures
- Training
- Resources and equipment
- Command and control
- Communications

4. SYSTEMS ANALYSIS

4.1 OVERVIEW

To safely and efficiently execute a rope rescue operation, it is necessary to have a sound understanding of the technical information and physics behind the decisions, strategies, techniques, and equipment in this manual. Additionally, this understanding must be applied through critical thinking during system analysis and the operational phase. **Critical Thinking** can be defined as the analysis of facts to form judgment.[5] Critical thinking and systems analysis of rescue systems form the foundation of safe, effective, and efficient rigging. It is one of many important components of good risk management during a rescue incident. Technical rope rescue is inherently complicated. There is nothing basic about it. Organizations and the critical thinking rescuer should be skeptical of simplification. [6]

4.2 UNITS AND TERMINOLOGY

Base Units are the fundamental physical quantities for a system of measurements from which other units are derived. For the International System of Units (SI) used in this manual (and in most technical rigging work) the base units are: second (s) for time, meter (m) for length, and the kilogram (kg) for mass.

Mass is the measure of the quantity of matter in an object. The term "weight" is the force of gravity on an object and is considered too ambiguous for rigging work.

Derived Units are units of measurement that come from combinations of base units. For example, velocity is distance per time or meters per second (m/s). The derived units most important to rope rescue work in SI are meters per second (m/s) for velocity, meters per second^2 (m/s^2) for acceleration, and kilonewtons (kN) for force (mass x acceleration).

What is a kilonewton and why is it important to rescue work? A newton is a derived unit of force in the SI unit system. Force is mass times acceleration. Acceleration is a change in velocity over time and written as meters per second per second (m/s/s), or as meters per second squared (m/s^2). An object with a constant velocity has no acceleration. The acceleration can be from any applied force whether that is the force of friction, gravity, or from a rope moving a rescue load up a cliff.

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[5] Wikipedia https://en.wikipedia.org/wiki/Critical_thinking

[6] Managing the Unexpected Weick, Karl and Sutcliffe, Kathleen

The acceleration due to gravity is a key value in rope rescue work and on earth is 9.81 m/s^2, which is often rounded up to 10 m/s^2 for ease of calculation during system analysis.

$$F = ma = mass\frac{meters}{seconds^2}$$

One newton is 1 kg times m/s^2. For reference, one newton is .2248 pounds (lbs) of force. 1 kN is 1000 Newtons. So, **1 kN is approximately 225 lbs**. In rescue work we assign a mass of 100 kg (225 lbs) to a rescuer or patient in our rope system.

$$Newton(N) = kg\frac{m}{s^2}$$

It is important to understand the force a rescuer exerts on a rope system so that we can perform an accurate analysis. When we enter those values into the above equation, we get a result of 1000 N. Therefore1 kN is the approximate force one rescuer (100 kg) exerts on a rope system when hanging in free space.

$$1kN = 1000N = 100kg \times 10\frac{m}{s^2}$$

Most climbing and rescue equipment manufacturers label their gear according to a minimum breaking strength (MBS) in kN. These numbers are based on the specific equipment's testing data. For this and other reasons discussed below we are building our rescue systems to a kilonewton standard.

4.3 STANDARD RESCUE LOADS

Description	**Mass**	**System International (SI) Force**	**Imperial units of force**
1 Rescuer + gear	100kg	1 kN	~225 lbs
Standard Rescue Load = 1 rescuer + gear + patient	200kg	2 kN	~450 lbs
2 Rescuers + gear +patient	280kg	~2.8 kN	~625 lbs

Figure 4.3-1 Standard Rescue Loads

4.4 MECHANICS AND FALL FACTOR

The area of physics concerned with the study of objects and motion is called **Mechanics.** **Mechanics** can be further broken down into statics and dynamics. **Statics** is the analysis of loads on physical systems that are not in motion (static), while **Dynamics** is concerned with the motion of objects and the associated forces. Isaac Newton's laws of motion are the foundation for the study of Mechanics.

Newton's Laws of Motion

1. An object at rest or in motion will stay at rest or in motion unless acted upon by a force.
2. F=ma
3. Every action (or force) has an equal and opposite reaction.

The analysis of dynamic systems involves calculus, is time consuming, and is not real time/world applicable. Because of the complexity of these fields as they apply to technical rope rescue, we utilize heuristics (rules of thumb) and testing to operate within reasonable margins of safety. Some of these tools such as critical thinking, mission profile, white board analysis, safety factors, and force limiting systems are described below.

The forces generated during dynamic events can be extreme. Climbing ropes are designed to elongate and dissipate these forces; however, other climbing software such as webbing, accessory cord, and low stretch rescue ropes are not. Rated tensile (break) strengths are determined by a slow pull failure or yield point during which forces are applied slowly to a material until it fails or yields to the point it is no longer usable. The yield point is the elastic limit where deformation begins. The potential for a dynamic event occurring in a worst-case situation (i.e., 1 m drop on 3 m of rope in service with a rescue-sized load) underscores the need to build a system stronger than the intended maximum rescue load. This worst-case situation has been historically used in testing of rescue systems and was developed by the British Columbia Council of Technical Rescue in the 1980s and is further explored below.

Fall factor is the distance of the fall divided by the amount of rope (material) available for absorbing the energy of the fall. It is a measure of the relative severity of a fall. Typically, a factor 2 fall is the highest encountered in a climbing situation, where the leader climbs above the belay anchor a distance and then falls that same distance below the anchor (Figure 4.4-1). This might involve falling 6 meters (20 feet) with 3 meters (10 feet) of

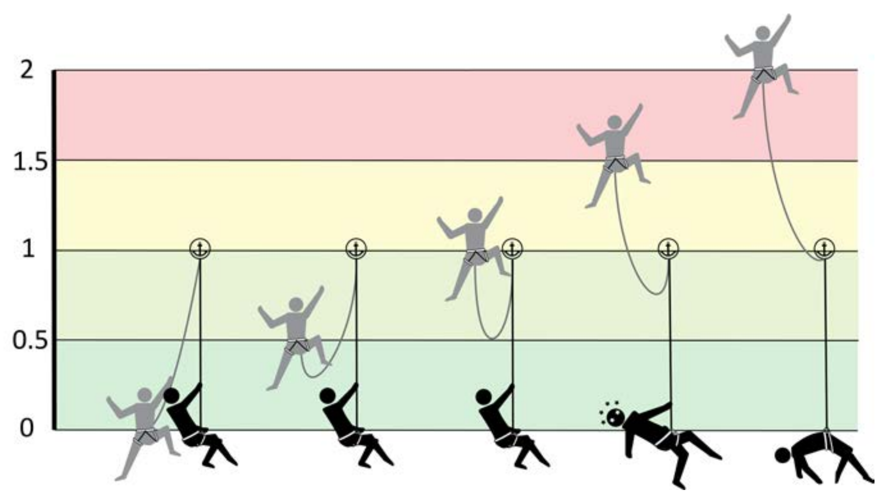

Figure 4.4-1 Fall Factor

rope available for energy absorption. A fall factor 2 on low-stretch rope (rescue rope) generates enough force to cause severe injury or death. An understanding and practical application of fall factor and the peak forces it generates is a critical skill in preventing catastrophic rigging and/or operational errors.

$$Fall\ Factor = \frac{Fall\ Distance}{Length\ of\ Rope\ In\ Service}$$

One potential scenario for generating extremely high shock forces in rope rescue is during an edge transition with a rescue-sized load and minimal rope in service. Another would be the careless introduction of slack on a working rope due to an inattentive belayer.

4.5 SYSTEMS ANALYSIS

After a basic understanding of rigging fundamentals and physics, the ability to critically analyze a system is essential. System analysis is an important component of risk management but should not be mistaken for an on-scene inspection. System analysis is a set of tools to be utilized in reviewing or starting a rescue program, planning a mission, or setting rigging standards like a Static System Safety Factor (SSSF).

Critical Thinking is the broadest concept to be applied to the systems analysis toolbox and should always be implemented. Utilize facts and data to form a strategy while avoiding the pitfalls of opinion.

A **Mission Profile** analysis matches the objective and the environment to the equipment, tactics, and personnel. For example, a team with roadside access to the top of technical terrain will not have concerns for weight savings like an alpine rescue team. By critically analyzing the mission profile, the best equipment and techniques can be selected to match the environment and objective of a team's mission.

White Board Analysis diagrams a system without exposing personnel to hazards. A Critical Point Test and a Whistle Test can be conducted during a white board analysis.

The **Critical Point Test** examines and locates single points that exist in a system where its failure results in total system failure (i.e., ground fall). If there is no redundancy at this point, then it is a "critical point". If a component is deemed critical then a redundant component should be added. The only true critical point in a rescue system should be a rescuer's harness.

A **Whistle Test** is an analysis of a system's "auto stop" as a design criterion that prevents catastrophe in the event of human error or a real accident like lightning or rockfall onto your system operators. An auto stop is a design characteristic that should always be implemented for any rescue system.

A **Comparative Analysis** should include an extensive pros vs cons list and a complete cost/benefits list. This can be applied to a single piece of equipment or to an entire system of rope rescue. A thorough Comparative Analysis should also include field trials and not be limited to only abstract thought.

A **Static System Safety Factor (SSSF)** is the ratio of the applied force to a rated tensile strength (break strength) of a piece of equipment when the load is not moving (static state).

As determined through testing of a worst-case scenario described below in the Belay Competency Drop Test Method (BCDTM; see Section 4.6 Testing), the maximum peak forces in a properly engineered system reach about 12 kN or less depending on the equipment used. "The rescue community is still struggling with what is the correct approach for a system design. In many cases, the ability to estimate the dynamic loads is beyond the ability of most rescuers in the field."[7] In engineering, a commonly applied Dynamic Safety Factor (DSF) is between 1.5 and 2 to 1. Due to the complexities of dynamic analysis a SSSF of 10:1 can be applied more simply and generally results in providing a DSF of 1.5-2:1.

By engineering a system with the weakest components having a 20-24 kN break strength, testing has shown that the yield point (failure) of equipment due to a dynamic event will not be reached.

"We find the application of safety factors to be among the most useful decision-making tools we have at our disposal. The practitioner seeking to simplify the System Strength decision-making process by applying a fixed kN value to the system engineering (as opposed to a safety factor, for example), may inadvertently handicap themselves by limiting their understanding of the statics and dynamics being represented."[8]

Based on the results of extensive testing, most mountain rescuers have adopted a 10:1 SSSF in rope rescue systems. When built to this standard, testing has shown that sufficient rigging strength will exist to withstand the peak force of a relative worst-case event and stay well below the breaking strength of the equipment.

Force Limiting Systems (FLS) approaches system analysis from the applied forces and not a fixed static system safety factor analysis. This approach has "essentially two requirements: the first is to limit, or cap the maximum arrest force of the relative worst case event to a value which humans can tolerate, and the second requirement is to ensure that the devices interacting between the rope and anchor provide sufficiently high friction or resistance such that any sudden 'jolt', or 'settling-in' of the load

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[7] Design Criteria for Rescue Systems, Attaway, Stephen. PhD., Personal correspondence. 2014.

[8] Two Tension or Not to Tension Gibbs and Koprek, Sec. System Strength. 2019.

onto the rope system does not result in excessive slippage, or worse."[9] In other words, the system is engineered such that ropes will slip through descent control devices, back-ups, and rope grabs during high force events in order to limit maximum arrest force. These peak forces are attenuated by slippage or "clutching". At the same time, the system must not "slip" too easily, otherwise, there is insufficient friction and loss of control can occur. Putting this into numerical requirements, FLS requires that all descent control devices, back-ups and rope grabs force limit between 6-12kN, and that the system strength must be 20+ kN (including testing of a rope loaded into a descent control device (DCD)[10].

OSHA requires a maximum arrest force of less than 8 kN for a person in a harness.[11] The design of conventional ropes used in rescue work today meet this force limiting criteria and act as the primary force limiting component. Additional force limiting can occur in ATCs, belay plates, scarabs, VT Prusiks, MPDs, etc., due to slippage through the devices. Additionally, all these commonly used devices have inertial runaway prevention if properly rigged i.e. ATC with a VT prusik (See Chapter 12).

4.6 TESTING

The final way to truly analyze a rope rescue system is by testing. Through testing, weaknesses and strengths of systems, equipment, and techniques can be determined. Testing is the data and fact-based foundation behind all systems analysis. A failure analysis involving destructive testing and human factor involvement is a critical part of any systems analysis.

The **Belay Competency Drop Test Method** was developed by British Columbia Council of Technical Rescue (BCCTR) in the early 1980s. Its purpose was to simulate the worst case scenario of an attendant and patient in a litter (200 kg mass total rescue load) slipping during the start of an abrupt edge transition and falling 1 meter on 3 meters of rope, which is a fall factor of 0.3. The belay system being tested must arrest this fall in less than 1 meter of additional travel, remain operable, and keep peak forces below 15 kN.

The BCDTM is often criticized as testing such an extreme situation that it does not expose our systems to more real-world failures. Through proper hazard mitigation the BCDTM scenario can be avoided through rigging more rope in service, using high directionals, varying the severity of an edge transition, or other force limiting techniques. Although the BCDTM has been a standard in testing for over 30 years and has resulted in more robust systems, it should be noted that it only tests equipment and does not evaluate any human factors in rigging or operating a system.

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[9] Dual Capability Two Tension Rope System Mauthner, Kirk, Sec. Force Limiting Principles, ITRS 2016

[10] Dual Capability Two Tension Rope System Mauthner, Kirk, Sec. Force Limiting Principles, ITRS 2016

[11] OSHA 1910.66, Appendix C, Section I, subhead d ("System Performance Criteria")

Human error has been reported as being responsible for 60%-80% of accidents in high risk industries.[12] Studies of climbing accidents attribute similarly 65%-90% to human error.[13] The last decade has seen more testing around human factors in rope rescue. However an increased focus on this is clearly warranted.

To produce data to support a valuable finding, testing should utilize proper methodology and acknowledge bias. Proper methodology should start with a null hypothesis which is a statement or position about a feature or equipment in a system. The testing should seek to disprove that null hypothesis. Test sets should include one variable and a control. A null hypothesis test method is an effective way to gain insight into a system and its weaknesses.

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[12] Human Reliability and the Cost of Doing Business D.L. DeMott SAIC – Sr. PRA/HRA Analyst, NASA Technical Reports Server

[13] Rock Climbing Rescues: Causes, Injuries, and Trends in Boulder County, Colorado Daniel A. Lack et al From the Rocky Mountain Rescue Group, Boulder, Colorado WILDERNESS & ENVIRONMENTAL MEDICINE, 23, 223–230 (2012)

5. EQUIPMENT

THIS CHAPTER PROVIDES INFORMATION ON STANDARD TECHNICAL RESCUE EQUIPMENT. RESCUERS SHOULD ALSO READ MANUFACTURER INSTRUCTIONS FOR USE, CARE, CLEANING, AND RETIREMENT GUIDELINES.

5.1 RESCUE EQUIPMENT

When used correctly, rescue ropes provide years of service and are built to withstand worst-case scenario peak forces. Most 11 mm rescue rope has a breaking strength of around 30kN and a knotted strength of approximately 20kN; sufficient for 10:1 SSSF and 1.5-2:1 DSF thresholds, as described in Chapter 4.

While rescue rope is very strong as far as withstanding peak forces, it has a problematic weakness: abrasion resistance. Rope cuts at a much lower force than it breaks. A rope that withstands a 30kN peak force can be cut across a sharp edge with as little as 4kN of force. Or, even less force during pendulum swings or repeated see-saw loading such as ascending[14]. For this reason rescuers must remain vigilant about padding edges, ensuring pendulum swings are not possible, and inspecting ropes after each use.

Important characteristics and properties to evaluate when comparing different rope materials include:

- Strength
- Abrasion resistance and durability
- Flexibility, handling and knotability
- Elongation (rope stretch)
- Heat resistance

ROPE MATERIALS

The following table provides information on modern synthetic materials. Nylon and polyester are the two most common materials used in constructing rescue ropes due to their balance of strength, abrasion resistance, knotability, and heat resistance.

[14] Kirk Mauthner, personal communication 2020

Generic, Trade Name	Breaking Tenacity* (gpd)	Melting Point	Abrasion Resistance	Other Notes
INDUSTRIAL FIBERS				
Polyamide (Nylon)	7.5-10.5	218° -258°C	Very good**	Pros: easy availability, inexpensive, good handling. Cons: absorbs water, will not float, weakens ≈20% when wet.
Polyethylene (Polyester)	7.0-10.0	254°-260° C	Very good	Pros: retains strength when wet, better UV resistance than Nylon. Cons: cost.
Polypropylene (PP)	6.5	140° C	Fair	Pros: floats; good for swiftwater. Cons: low melting point.
HIGH TENACITY FIBERS				
Polyester-Polyarylate, Vectran®	23-29	330° C	Very good	Pros: very strong, low stretch. Cons: poor resistance to UV light, not typically used for SAR work.
Para-Aramid, Kevlar®	18-29	500° C ***	Fair	Pros: high heat and abrasions resistance. Cons: high cost, may be damaged by repetitive bending / knotting.
Para-Aramid, Twaron®	20-29	500° C ***	Fair	Similar to Kevlar.
HMPE, Spectra®	25-41	150° C	Excellent	Pros: 10x stronger than steel. Cons: low melting point.
HMPE, Dyneema®	32-44	144°-155°C	Excellent	Pros: 10x stronger than steel. Cons: low melting point.

Figure 5.1-1 Comparison of rope materials
Denier is a unit of fineness or density of yarn based upon 50 milligrams per 450 meters. (ASTM D885)
** Breaking tenacity is a measure of the strength of a yarn fiber measured in grams per denier (gpd).*
*** Nylon has very good abrasion resistance when dry and poor when wet*
**** Does not melt, decomposes at 500° C*

ESTABLISHED ROPE CLASSIFICATIONS

Dynamic Rope — A rope made to absorb energy by stretching, but not to exceed 40% elongation in the first UIAA test fall. These ropes are typically not used in technical rescue, rather, they are used as lead ropes in climbing applications.

Low-Stretch or Semi-Static Rope — A rope with 6%-10% elongation at 10% of MBS.[15]

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[15] Cordage Institute website: https://www.ropecord.com/new/terminology.php#D.

Static Rope — The lowest-elongation category. Static rope has a maximum elongation of 6% at 10% of MBS.[16] Static rope is the most common classification of rope employed by rope rescue teams.

ROPE DIAMETER

Mountain rescue primarily utilizes 11 mm (7/16 inch) diameter static rope, which has 27-40 kN (7870 lbf) breaking strength depending on brand and construction.

Due to improvements in materials and rope construction some alpine rescue teams are utilizing smaller diameter ropes that have break strengths around 30kN. These ropes have advantages in weight savings and packability but their disadvantage is less durability. Extra caution and additional training is needed for the use of these ropes due to the decrease of abrasion resistance and the lack of compatibility with some descent control devices. Two examples are New England Ropes KMIII 9.5 mm (3/8 inch) with 30kN Max Break Strength (MBS) and Sterling Workpro 10.0 mm (3/8 inch) with 29 kN MBS. A limited number of high-alpine rescue teams also use 8 mm Dyneema ropes but this is considered highly specialized and requires additional training.

ROPE LENGTH

Mountain rescue teams typically develop preferred lengths based on their local operating area. There is no industry standard but common working rope lengths include 150, 200, 300 and 600 feet. Longer lengths are employed in some areas; however, transport to remote sites becomes a challenge. Teams also cut short 50 ft sections as "anchor ropes" to assist with topside rigging applications including edge lines and anchor rigging. Recreational climbing employs dynamic ropes ranging in length from 30 to 80 m (98-262 ft) long, with 60 m being the most common (195 ft). Rescue ropes should have ends labeled with the length, diameter, in-service date and a numerical designation for tracking use (Figure 5.1-2).

Figure 5.1-2 - Rope label. Provides identification number, diameter, length and in- service date.

ROPE TERMINOLOGY

Knotability— Ability of a life safety rope to hold a knot.

Minimum Breaking Strength (MBS)— The force that a given rope is required to meet or exceed in a laboratory test when it is new and unused.

Working Load (WL)— The weight or force applied to rope or cordage in a given application.

[16] Ibid.

Working Load Limit(WLL)— The WLL, also referred to as Safe Working Load (SWL), is a guideline for the maximum allowable capacity of a rope product and should not be exceeded. The WLL or SWL for rope is described as a ratio of the MBS to load on a rope. NFPA and OSHA recommend a 10 to 1 SWL for life safety rope[17].

CARE AND USE OF ROPE

- Don't step on ropes.
- Ropes should be stored away from acids and sunlight.
- Nylon is made from petroleum. Consequently, petroleum products don't deteriorate nylon rope. However, they should be kept away since it will attract dirt.
- Become proficient at coiling and throwing a rope.
- When storing a rope remove all knots.
- Store in a rope bag (Figure 5.1-3).
- Identify individual ropes with secure labels.
- Document use history with a rope log.

Figure 5.1-3- Rope bag. Provides protection and eliminates the need to coil a rope.

BAGGING A ROPE

Keeping a rescue rope stored in a rope bag provides protection from dirt, abrasion and ultraviolet rays. The recommended technique for bagging a rope (Figure 5.1-4) is to initially tie one end of the rope to a loop of webbing at the mouth of the bag which will keep it accessible. Stuff the remaining rope directly into the bag. Tie off the other end of the rope at the mouth of the bag as well to provide easy access during deployment.

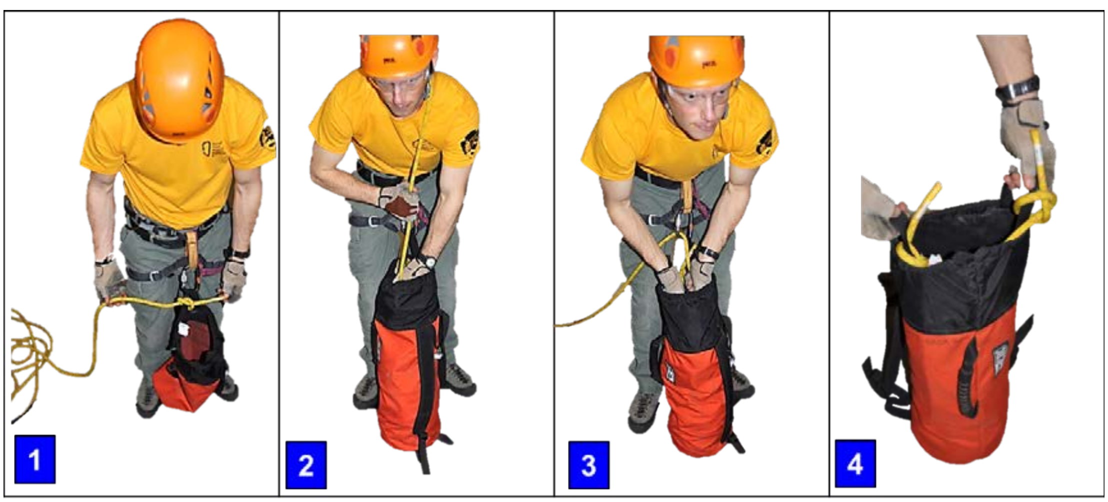

Figure 5.1-4 — Bagging a rope. 1. Tie off the initial rope tail to the mouth of the rope bag. 2. Rope can be directed over the shoulder into the bag. 3. Alternate technique is to direct the rope through a carabiner on a harness into the bag. 4. Securing the rope terminus to the mouth of the bag.

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[17] Sterling Rope. Guide to Rope Engineering, Design, and Use- Volume 1.X

THROWING A ROPE

First make certain you are attached by a safety line to permit you to stand safely at the cliff edge. Attach one end of the line to be thrown to the anchor system. Make large looped coils of the rope in one hand starting with the anchor side and working toward the end that will be thrown over. When half way completed in forming the coils, separate the second half from the first half with your index finger.

Evaluate the wind and terrain. Yell "rope!" to alert anyone below you. First, throw only the uphill section of coils, closest to the anchor, with enough power to overcome any wind. The rope will be partially deployed down the cliff and stretching back to the remaining coils in your hand. Next, throw the lower section of coils with a powerful shot aiming 45 degrees out and away from the base of the cliff. This should permit the remaining rope to fold outward and down with significantly less likelihood of entanglement. In some cases a snagged rope can be freed by a rescuer during a rappel, but it is often best to pull the rope back up, recoil it and throw it again.

Some rescuers prefer to deploy the rope from a rope bag attached to them as they rappel. The advantage of this technique is that there is no rope beneath the rappeler to generate rockfall or get tangled. However, it is difficult to know how much rope remains in the bag or the rescuer may encounter a rope tangle coming out of the bag. Place a stopper knot at the end of the rope prior to use to eliminate the chance of rappelling off the end!

Deploying a rope by means of throwing a loaded rope bag from the top of a cliff with one end secured to an anchor is possible, but has some disadvantages: the bag is a heavy projectile and could cause injury or death to someone below. Also, if the rope needs to be pulled up and thrown again the bag attached to the rope will possibly become entangled. Use this technique with caution.

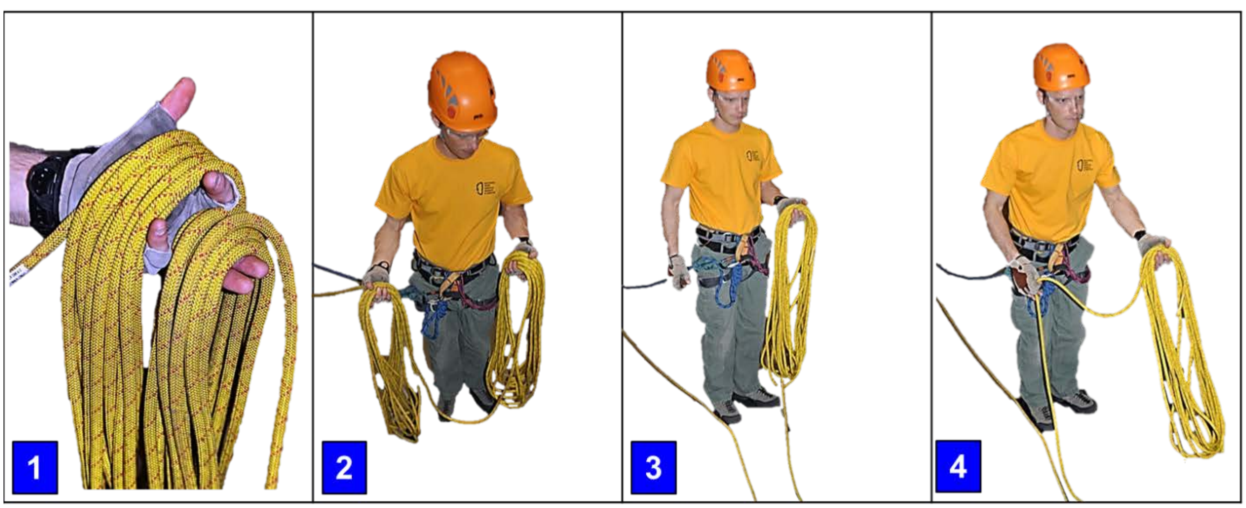

Figure 5.1-5 — Throwing a rope. 1. While forming the coils, they are separated in to two halves to permit an easy split. 2. Spilt the coils in half. 3. Initially throw the "uphill" half attached closest to the anchor. 4. Finally throw the remaining "downhill" half, which folds over the section previously thrown.

COILING A ROPE

BUTTERFLY COIL — The butterfly coil is typically a faster procedure for coiling a rope and allows for the rope to be tied snugly against the body (Figure 5.1-6). Begin by finding the mid-point of the rope and double it back upon itself, so the entire rope is folded in half. Start with the mid-point and begin making large horseshoe coils on either side of your hand, or either side of your neck. Continue making coils until 2.4 m (8 ft) of the doubled rope remains. Lift the looped rope off your shoulders and fold it at the center of the horseshoe. Use the 2.4 m (8 ft) of loose rope to make three or four wraps around the entire bundle. With the remaining 1.2 m (4 ft) of rope, make a bight through the top of the coil where your hand was holding it. Insert both ends of the rope through this bight and tighten it to secure. Wrap one strand over each shoulder with the coil on your back. Bring the ends around to the front of your waist and tie to carry like a backpack.

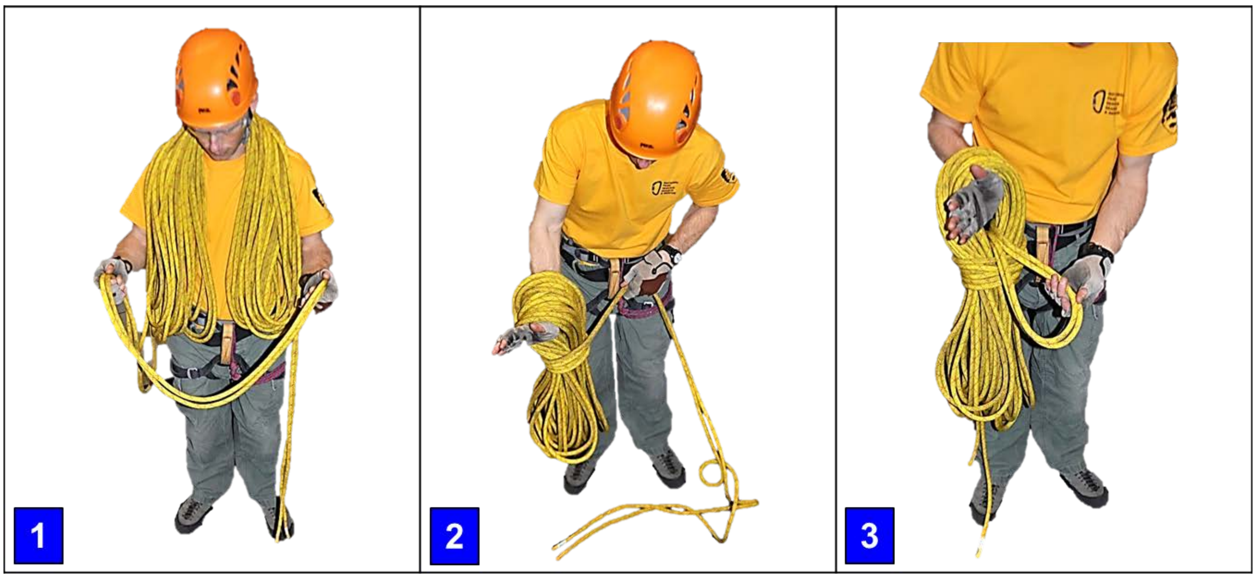

Figure 5.1-6 — Butterfly coil. 1. After folding the entire rope length in half and starting with the midpoint, make large horseshoe coils over your neck, which extend down to your waist. Continue until 2.8 m (8 ft) of rope remain. 2. Remove the folded coils from your neck and with the remaining tail make four wraps around the entire bundle. 3. In the last 1.2 m (4 ft) make a bight and pull it through the top of the coils. Pull this bight over the top and lock in place by pulling on the rope tails.

Procedure for Inspecting Ropes

All rescue ropes should be inspected for wear and damage after use. The inspection process includes both visual and tactile inspection. Tactile inspection involves the same examiner feeling the entire length of the rope being evaluated, regardless if only a portion of the rope was used. Dirty ropes should be cleaned prior to inspection.

ACCESSORY CORD

Low-stretch nylon accessory cord, which is also made with kernmantle construction, is a very versatile item used to construct cordelettes, Purcell Prusiks, jiggers, and other items. 8 mm cord should be used when rescue loads will be involved. Smaller diameters may be used for single person applications such as 6 or 7 mm for Purcell Prusiks. Prusik specific cordage must be used when tying Prusiks as the material needs to be sufficiently supple.

WEBBING
The most common webbing employed for general rigging by rope rescue teams is 25 mm (1 inch) tubular nylon webbing (needle loom construction). This is manufactured according to military specification, which requires a minimum breaking strength of 17.93 kN (4,000 lbf).

WEBBING PRODUCTS
Anchor straps, daisy chains and etriers (sewn stirrups) are all sewn webbing products used in technical rescue applications.

While convenient to use, there are limitations with sewn lanyards and it is possible to dangerously misuse them in certain rigging applications. Mike Gibbs of Rigging for Rescue prepared a comparative analysis titled Daisy Chains and Other Lanyards, which led to the conclusion that “when using a lanyard as the only means of attachment to an anchor; keep unnecessary slack out of the lanyard, thereby keeping the potential fall factor low.” [18]

CARABINERS

Mountain rescue carabiners typically need to have a minimum breaking strength of 20kN. Aluminum is preferable to steel for weight savings. The specific parts of a carabiner include the body, spine, gate, nose, hinge and sleeve. The major axis of a carabiner refers to an orientation end-to-end along the spine, while the minor axis refers to an alignment across the carabiner side-to-side (Figure 5.1-7).

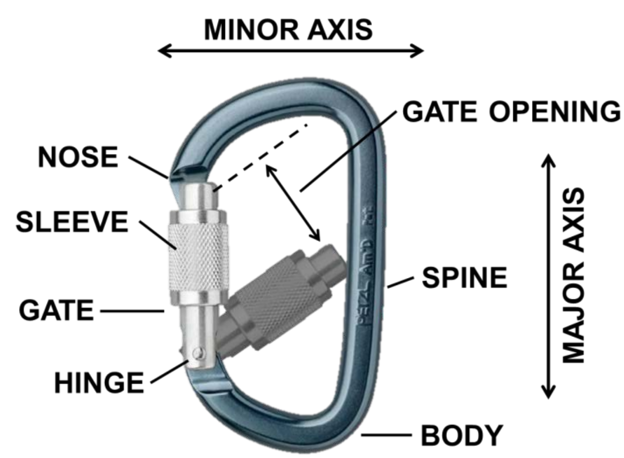

Figure 5.1-7 — Carabiner nomenclature. Original image © Petzl.

LOCKING STYLES
Non-locking— These carabiners are used in non-critical points, such as securing edge protection, or when clipping several bolts that will be combined into one anchor with a cordelette. These carabiners are never used at critical points. A critical point in the system is a point at which if the carabiner failed, the entire system would fail. Use locking carabiners at critical points instead.

Screw Lock— Features a threaded sleeve that must be manually screwed open or closed in order to release the gate. They have fewer moving parts than spring-loaded mechanisms, are less prone to

[18] Gibbs, Mike. Daisy Chains and Other Lanyards. p.6

malfunctioning due to contamination or component fatigue. They are more time-consuming to operate than twist-lock.

Auto-Locking (Twist Lock)— These have a security sleeve which must be manually rotated to unlock and open.

CARABINER SHAPES

Carabiners are manufactured in several popular shapes (Figure 5.1-8), which primarily include:

- Oval — Symmetrically shaped with smooth regular curves. The oval design places the load on both the solid spine and the gate side.
- Asymmetrical D-shape —The asymmetrical lopsided shape transfers the majority of their load onto the spine, which is the carabiner's strongest axis.
- **Modified/Offset-D —** Very similar in design and function as a D-shape carabiner. The main difference is the exaggerated asymmetrical design, allowing for a wider gate opening.
- **Pearbiner/HMS —** Specialized oversized offset-D (pear-shaped) used in belaying and in conjunction with the Italian Hitch. HMS is an acronym for "Halbmastwurf sicherung," which in German means "half clove hitch," another name for an Italian Hitch.

Figure 5.1-8 — Carabiner Shapes. Images © Petzl

SCREW LINKS

Screw links may be used as a connector when multi-directional forces are anticipated. This is typically at the chest harness / connector strap interface, in some litter bridle configurations, and in some basket hitch anchors and anchor straps. Minimum breaking strength for all shapes certified for climbing and mountaineering applications (CE EN 362 and EN 12275) in the closed and locked position should be: major axis 25 kN and minor axis 10 kN.

RESCUE PULLEYS

A rescue pulley (Figure 5.1-9) has rotating side plates and is constructed with a sheave (wheel) mounted on a bearing or bushing. Pulleys constructed with sealed bearings are superior and more efficient in handling rescue loads than those containing bushings.

Figure 5.1-9 — Rescue pulley. Rock Exotica Mini Machined Pulley (P21). © Rock Exotica.

The tread diameter of the pulley sheave, where the rope lays, is important to note. For efficiency, the optimum rescue pulley size would be a tread diameter of at least three times the diameter of the rope being used on it. Some manufacturers will state the outside diameter (OD), which could be misleading. Pay attention to the tread diameter which relates directly to performance[19].

Knot Passing Pulley — The wide sheave The Kootenay Ultra by Rock Exotica permits knot passing and has a locking sheave to create a high strength tie-off (Figure 5.1-10). It is also purpose-designed for highlines as there are separate connection holes for tag-lines and reeve-lines, and a sheave that is wide enough to run over multiple track-ropes.

Prusik-Minding Pulley. CMC Rescue ProSeries® Pulley with side plates shaped to tend Prusik Hitches.

Double Sheave Pulley. Rock Exotica Omni-Block Swivel Pulley. Design allows opening the side plate while clipped to an anchor and has becket attachment point at the base.

Rock Exotica Kootenay Ultra. Specialized pulley with wide sheave to permit knot passing or serve as travelling carriage in a highline system.

Figure 5.1-10 — Pulley Types. © CMC Rescue and Rock Exotica.

[19] Thompson, Rock. Personal communication.

DESCENT CONTROL DEVICES (DCD)

SCARAB®

The Scarab® (Figure 5.1-11) is a compact variable friction descent control device (DCD) developed by Rick Lipke, Conterra Technical Systems. An advantage of the Scarab is that it is easy to vary friction during the lower by adding or subtracting horns. Proper training is required to ensure adequate friction especially during edge transitions where peak forces are possible. Read the manufacturer's instructions for further information.

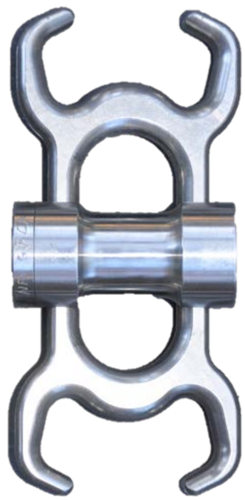

Figure 5.1-11 — Scarab® Descender manufactured by Conterra.

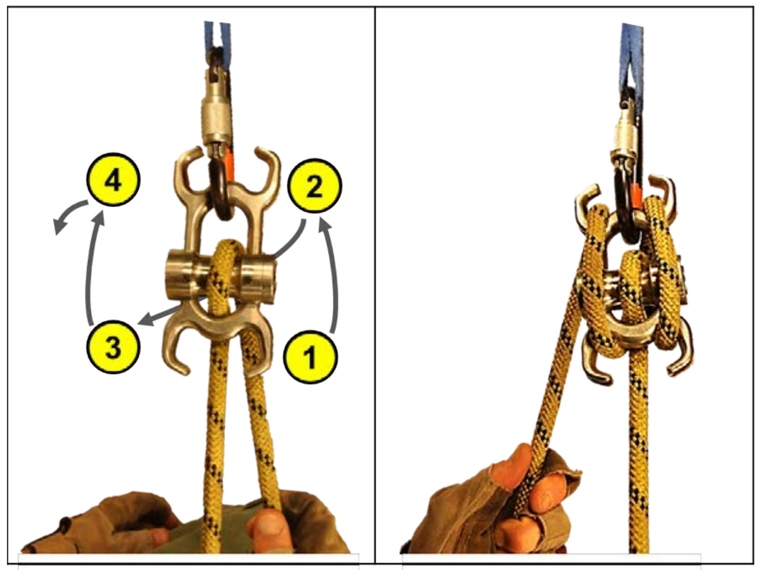

Figure 5.1-12 — Scarab usage. Proper threading sequence of a rope into the Scarab is shown above.

ATC —: The Black Diamond ATC Guide® is a rappel / belay device that can also be used as a rescue system DCD. See further information on proper use in Chapter 12.

PURPOSE BUILT DEVICES —The CMC MPD and CMC Clutch are both purpose built rescue combination pulley / DCD / belay devices. Consult manufacturer instructions and also see Chapter 12 for information on use.

DCD TIE-OFF NOTE — This handbook recommends the following consistent method for tying off all DCDs in the same manner for simplicity. The anchor side of the rope is tied off in front of the device with a half hitch followed by an overhand knot. This typically first requires that a bight of rope be pulled through the attachment carabiner behind the device.

Figure 5.1-12 — Prusik Hitch

PRUSIKS

PRUSIK HITCH — Prusiks should be tied with Prusik specific accessory cord, or be purchased commercially pre-sewn. The material must be supple in order to effectively grab the rope. Stiff accessory cord creates dangerous and ineffective Prusiks.

Figure 5.1-13 — Bluewater VT Prusik. © Bluewater

BLUEWATER VT PRUSIK— This commercially pre-sewn Prusik is made of a Technora aramid sheath with a nylon core (Figure 5.1-13). The Technora sheath makes it heat and wear resistant. The sewn eyes allow the Prusik to be tied in many configurations (e.g., a 3 wrap Prusik or an asymmetrical Prusik). The end to end tensile strength is 20 kN with an overall length of 33".

Figure 5.1-14 — Petzl Ascension Ascenders (Pair- right & left). © Petzl.

ASCENDERS

MECHANICAL ASCENDERS—Handled ascenders (Figure 5.1-14) are designed to be easily attached to and removed from a fixed rope, providing an efficient personal rope ascending tool. Mechanical ascenders are rated by manufacturers only for one-person loads.

RIGGING PLATES

The focal point of an anchor system can be kept organized with the use of a rigging plate. This simplifies multiple tasks or connections occurring at a single location and helps to keep lines orderly (Figure 5.1-15). The same objective can also be accomplished by tying a double bowline on a bite or double figure eight on bite.

Figure 5.1-15 — Rigging Plate. Keeps multiple connections organized.

5.2 MANUFACTURER BREAKING STRENGTHS OF RESCUE EQUIPMENT

ITEM	kN	Force pounds
CORDAGE/ROPE:		
4 mm Accessory Cord	3.9 kN	720 lbf
5 mm Accessory Cord	5.2 kN	1,125 lbf
6 mm Accessory Cord	8.8 kN	1,620 lbf
7 mm Prusik Cord	12.4 kN	2,200 lbf
8 mm Prusik Cord	15.6 kN	2,875 lbf
11 mm Static Nylon Rope (7/16 in)	30 kN	6,000 lbf
12.5 mm Static Nylon Rope (1/2 in)	40 kN	9,000 lbf
WEBBING:		
1 inch Mil-Spec Tubular Webbing (PMI)	18 kN	4,000 lbf
1 inch Type 18 Woven Flat Webbing (PMI)	27 kN	6,000 lbf
Black Diamond 10 mm Dynex Runner	22kN	5,000 lbf
HARDWARE:		
Petzl Minder (Prusik-Minding) Pulley (P60A) (97% efficiency)	36 kN	8,093 lbf
Rock Exotica 2.0 Prusik Minding Pulley	36 kN	8,093 lbf
Rock Exotica Omni-Block 2.0 Pulley	36 kN	8,093 lbf
CMC MPD	44 kN	9,891 lbf
CMC Clutch	40kN	8,992 lbf
Conterra Scarab	40kN	8,992 lbf
Petzl Delta Triangular Screw-Link, 10 mm (P11)	25 kN	5,620 lbf

Note: 1 Kilonewton (kN) = force of 225 lbs

Source: Manufacturer websites. MBS varies between manufactures and models.

5.3 PERSONAL PROTECTIVE EQUIPMENT

Agencies are required to provide PPE to employees at no cost [OSHA 29CFR 1910.132(h)(1)]. An agency may permit employees to utilize their personally owned PPE. However, the agency is required to inspect such equipment. *OSHA 29 CFR 1910.132(b)*

Additionally the employing agency is required (OSHA 29 CFR 1910.132(f)) to provide adequate training in the use of PPE, which includes:

- When PPE is necessary
- What PPE is necessary
- How to properly don, doff, adjust, and wear PPE
- The limitations of the PPE
- The proper care, maintenance, useful life and disposal of the PPE

Figure 5.3-1 — PPE ensemble for technical rescue

HELMETS

Rescuers should always wear helmets when operating in technical terrain. Ensure proper fit, both of the headband and chinstrap.

Figure 5.3-2 — Petzl Alveo Vent Helmet. Incorporates four-point chin strap restraint design and ratchet to adjust headband. © Petzl.

HELMET RETIREMENT

Helmets subjected to a significant impact should be retired from service immediately. A helmet that is dented, cracked or damaged should be retired immediately.[20] Helmets with no visible damage or known impacts should be retired after 10 years.

HARNESSES

Choose a harness compatible with the mission profile. Industrial style harnesses provide more padding and comfort, but create a burden when they must be carried. Select a lightweight climbing harness for backcountry rescue.

Rescuers should "tie in hard" to a harness rather than clipping the rope to the harness with a carabiner. Having the intermediate connection of a carabiner to the harness introduces one additional point of potential rigging error or equipment failure.

Figure 5.3-2 — Black Diamond Solution Guide Harness

INSPECTION

Harnesses must be carefully inspected before and after use. In rescue systems, typically the only true critical point which has no backup is the harness. Inspect webbing, buckles, and stitching and

[20] REI, Climbing Helmet: How to Choose. http://www.rei.com/learn/expert-advice/climbing-helmet.html

retire when there are signs of wear, or after seven years.

Chest Harness— A chest harness is worn in conjunction with a seat harness and helps to a keep the wearer upright in the event of a fall in steep or overhanging terrain. Depending upon the application, use of a chest is optional based upon on the likelihood of an inverted fall.

- A ***connector strap*** creates a sliding link between the seat and chest harness, which keeps a rescuer upright if they lose consciousness (Figure 5.3-4). This connector strap should be incorporated when the main line and belay line are joined together somewhere above the rescuer (e.g. rescue litter master attachment point) and the rescuer is in vertical or overhanging terrain. Although a tied piece of webbing is frequently utilized in this application, it is recommended that such a strap be a commercially sewn rated sling for added security. It is important that the connection between the seat harness and chess is snug to make certain that weight is transferred appropriately.

Figure 5.3-3 — Petzl Voltige Chest Harness. © Petzl.

Figure 5.3-4 — Connector Strap (Blue) Provides Link between Seat and Chest Harness.

PERSONAL EQUIPMENT

- **Cutting Tool—** a person wielding a sharp knife around tensioned ropes is dangerous. Trauma scissors or a rescue hook knife are recommended.
- **Eye Protection—** sunglasses or clear safety glasses.
- **Headlamp—** should be carried at all times.
- **Footwear—** with a sole that provides good traction.
- **Gloves—** supple leather rigging gloves.
- **Radio Chest Harness—** Protects expensive communications equipment and keeps it accessible.
- **Hearing Protection—** Ear plugs or other lightweight hearing protection to be employed when working around helicopters.

WHAT NEEDS TO BE ON YOUR PERSONAL HARNESS?

Keep equipment on your harness organized and to the minimum. Put the remainder of personal equipment in your pack where it can be accessed if needed. Avoid having gear suspended on your harness that hangs down below mid-thigh, which will tend to become entangled in vegetation, other rigging or a pant cuff when you kneel. Essential items for your harness:

- Belay/rappel device (ATC works well)
- Lanyard (Purcell Prusik works well)

- Means to ascend the rope (Purcell Prusiks, Tiblocs, ascenders, etc…)
- Prusik for rappel backup (VT, autoblock, etc…)
- Leather gloves, snug and thin with good dexterity
- Cutting tool
- Locking carabiners (half dozen is plenty)
- Non-locking carabiners (one or two)

Figure 5.3-5 — YOSAR rescuer with radio chest harness.

SUBJECT HARNESSES

A subject harness should be capable of being donned without requiring the individual to step into the harness. Commercially sewn harnesses are generally superior to improvised webbing harnesses both for ease of use and general comfort.

Lifesaver Victim Harness™— the CMC Lifesaver Victim Harness™ is a rescue harness with color-coded straps. The Lifesaver Victim Harness™ can accommodate up to a 157 cm (62 in) waist and weighs 1.3 kg (2.86 lbs).

Figure 5.3-6 — CMC Lifesaver Victim Harness™. © CMC Rescue.

RETIREMENT[21]

Retire gear when necessary, including:

- When over ten years old for plastic or seven years for textiles.
- When subjected to a major fall or impact force.
- When it fails to pass an inspection.
- If the reliability of the equipment is in question.
- The usage history is unknown (e.g., not marked, missing rope log, etc.).
- Obsolete design due to changes in standards, technique, or equipment compatibility.
- Check all carabiner surfaces regularly for cracks, sharp edges, corrosion, burrs or excessive wear. Hairline cracks can result in significantly reduced carabiner strength.
- Retire carabiners if they are dropped a significant distance, show excessive wear, or if the gate no longer functions.
- When equipment is retired, destroy it to prevent further use in a life safety application.

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[21] Adapted from Petzl— "Tips for Protecting Your Equipment"

http://www.petzl.com/files/all/technical-notice/both/protecting-equipment-tips_EN.pdf

6. KNOTS, BENDS, AND HITCHES

6.1 INTRODUCTION

Knots are a foundational element of rigging that enables rescuers to build rescue systems. Knowing the basic knots is a prerequisite to everything else that follows in this handbook. Factors that make certain knots or ties superior to others include the tendency of the knot to remain snugly tied, ease of untying and relative strength.

Figure 6.1-1 Properly dressed figure 8 knot.

As a general rule, *a knot in rope reduces the strength of the rope by one-third.* (A knot in tubular webbing decreases the strength by at least 45%.) This is due to sharp bends in the rope created by the knot. The strength of the knot will be affected by the sharpness of these bends and the angle at which the rope leaves the knot.

Knots should be properly dressed by "setting" the knot: pulling on each strand and tail. Riggers should eliminate loose spots or unnecessary twists in a knot.

For most knots, setting the knot and leaving adequate tail length eliminates the need to tie a separate backup or safety knot. This tail length should be approximately one hand-width for 11 mm rope or 3 inches for webbing (Figure 6.1-1). For smaller cord, the tail length needs to be six times the cord diameter[22]. An exception is the bowline family of knots, which is prone to loosening when not under tension and requires a backup knot. The backup knot is tied with excess tail using a double overhand knot. A half hitch does not make an acceptable backup knot.

6.2 ROPE AND KNOT TERMINOLOGY

Common terminology is used to refer to specific portions of a rope as well as describe types of knots (Figure 6.2-1):

[22] Lipke, Rick. Technical Rescue Rigger's Guide. p 17.

Working end: The active end of the rope used to tie the knot. Commonly connected to litter.

Working Part: The section of rope between the working end and the running part. Easily defined by the part of rope under tension; aka load side.

Running Part: The part of the rope used to control systems or friction; aka control or slack side.

Bight: Created by grabbing the rope and forming a tight U-turn shape.

Loop: A circle formed in a rope by crossing a bight over itself.

Elbow: A loop that is rotated once more.

Standing Part: Part of rope between the standing end and running part of rope.

Standing End: The end of the rope not active in knot tying. A rope system may have multiple standing parts/ends depending on your focus at any given time.

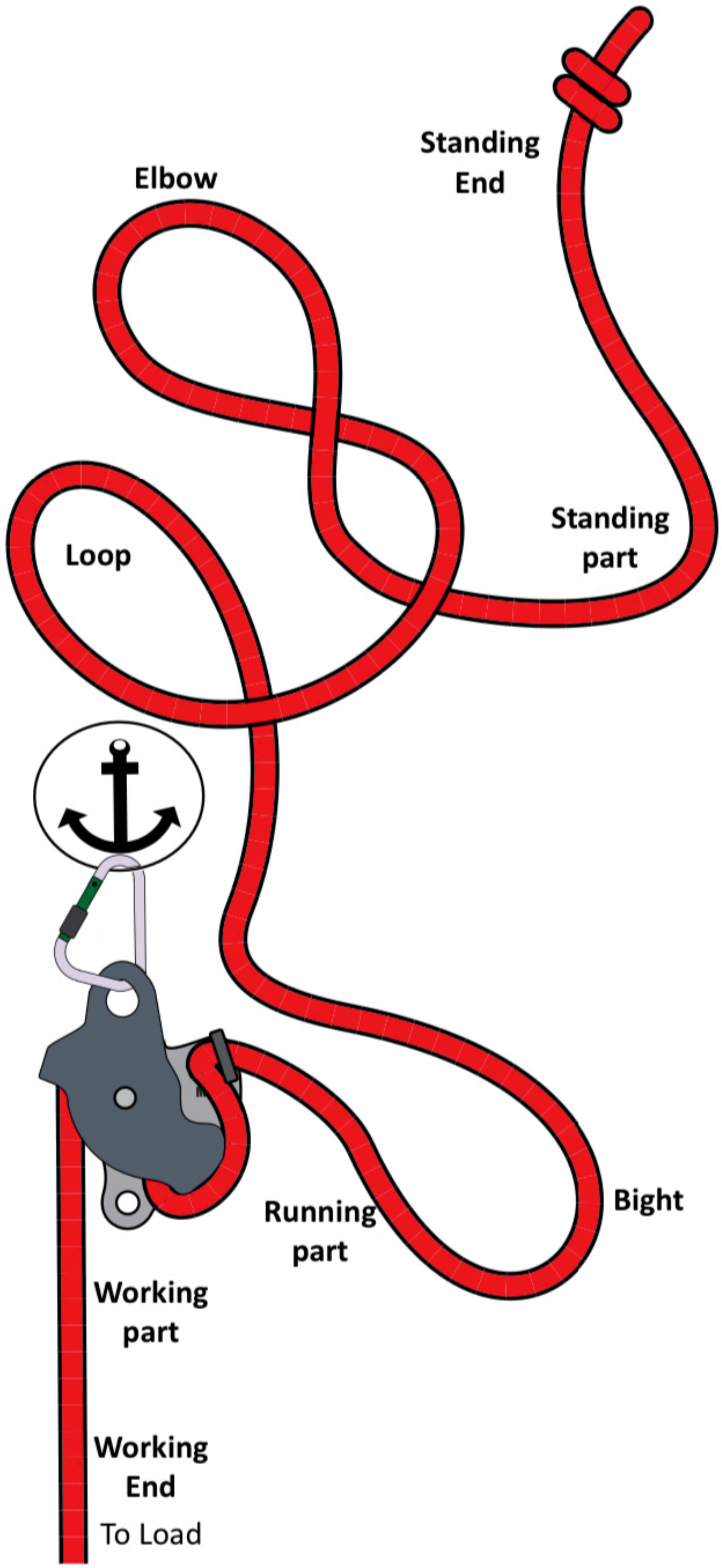

Figure 6.2-1 - Rope Terminology

- BEND: A tie that joins two rope ends.
- HITCH: A tie that attaches a rope to another object in a means that if the object is removed, the hitch falls apart (e.g., clove hitch).
- KNOT: A tie that intertwines within itself.
- SPLICE: Joins two ropes by interweaving the strands (not typically used in rescue).

6.3 KNOTS, BENDS AND HITCHES

NOTE: The following section of textbook provides illustrations of rescue related knots, bends and hitches. For detailed step-by-step instructions, please refer to various resources available on the internet including animatedknots.com™.[23]

KNOTS

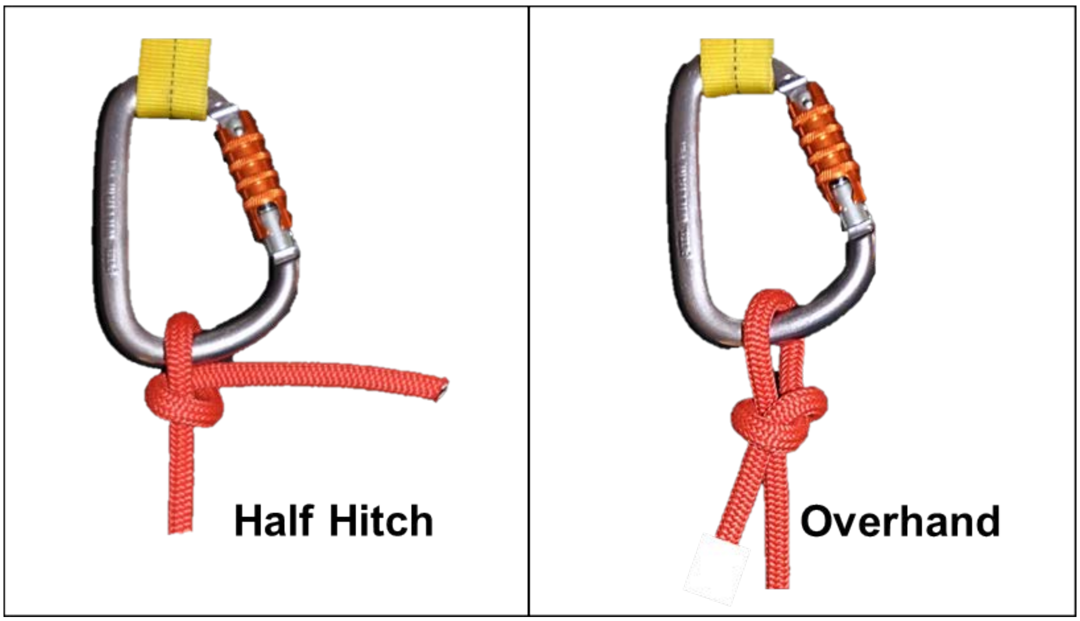

Figure 6.3-1 - Half Hitch and Overhand Knot secured to a carabiner

Overhand Knot

The overhand knot (Figure 6.3-1) is one of the simplest single strand knots. It is incorporated as a structural element in many other knots including the double fisherman's bend and ring bend. The double overhand knot is the preferred backup knot as it cinches in on itself and is less prone to 'springing open' with time and cycling as can occur with a single overhand knot.

Figure Eight Family of Knots

Figure eight knots are a very versatile group of knots that are simple to tie, easily inspected, and all share a characteristic figure eight loop in their structure (Figure 6.3-2).

- Figure eight (Flemish) knot - Forms a stopper knot that can be easily untied. It forms the foundation used in other knots within the figure eight family
- Figure eight on a bight - A simple means of tying a bight at the terminus of a rope which can be attached to an anchor point.
- Figure eight bend (Flemish bend) - May be used to join to two ropes together, though a double fisherman's knot or flat overhand is generally superior for this application.

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[23] Grogono, Alan, David and Martin. Animated Knots by Grog. http://www.animatedknots.com/

- Double loop figure eight - Provides two secure bights at the terminus of a rope for rigging, which can be identically sized or different depending on rigging requirements.
- In-line figure eight - Creates a uni-directional load-bearing loop in the middle of a rope. See the alpine butterfly for a multi-directional midpoint loop.

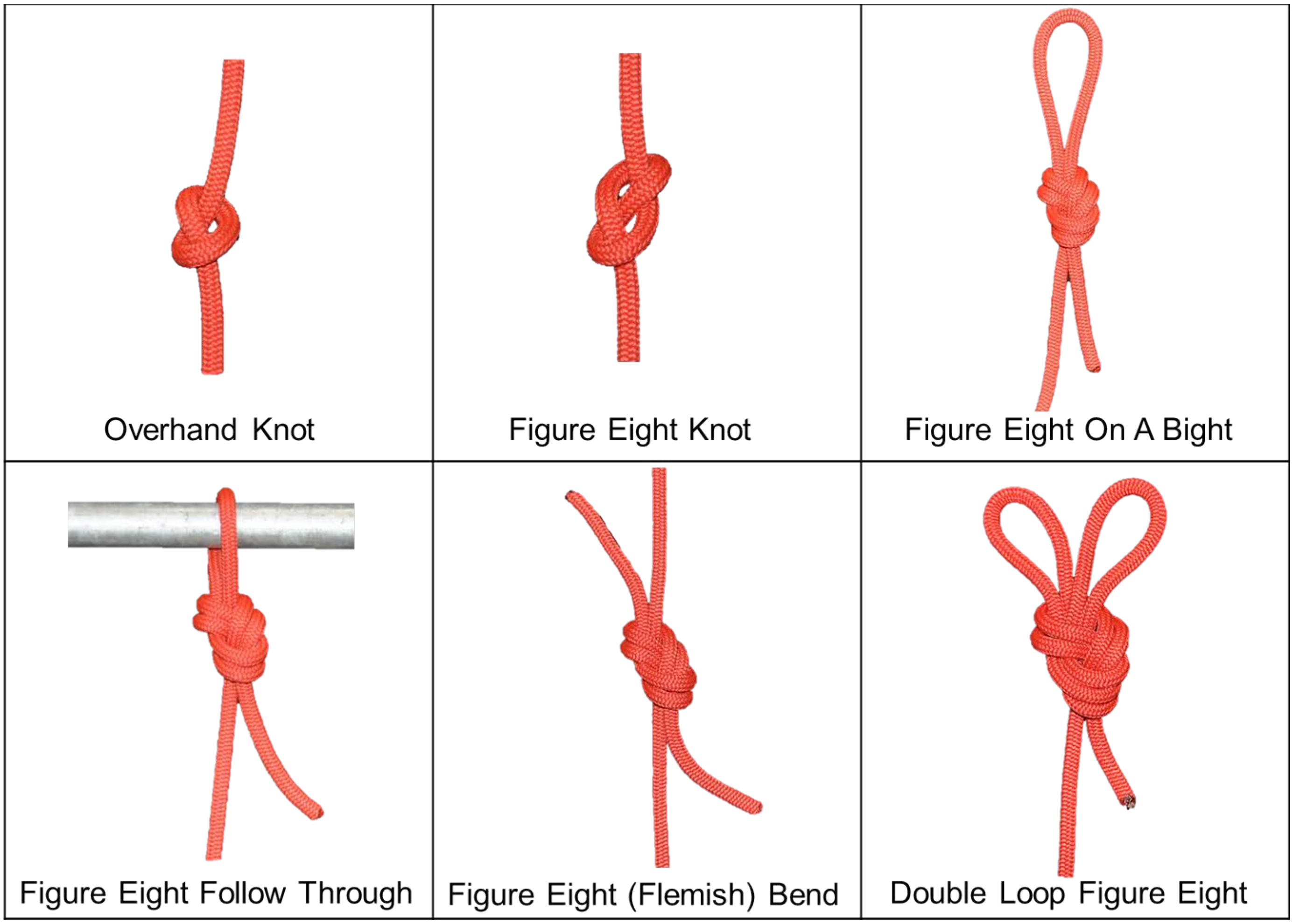

Figure 6.3-2 - Overhand and Figure Eight Knots

Bowline

The bowline is an ancient maritime knot from the 13th century which creates a fixed loop (Figure 6.3-3). Although the bowline is an efficient knot, it can work itself loose under repeated loading, therefore it is essential to tie a backup knot to secure the tail. It is recommended that a double overhand knot be used for this backup application. An advantage of the bowline is that it is easier to untie after being placed under tension and it is easier to adjust than figure eight counterparts. "*It (Bowline) is considered one of the preferred knots and a "must know" for rigging.*" — Bruce Smith, Author, ON ROPE, Revised Edition.

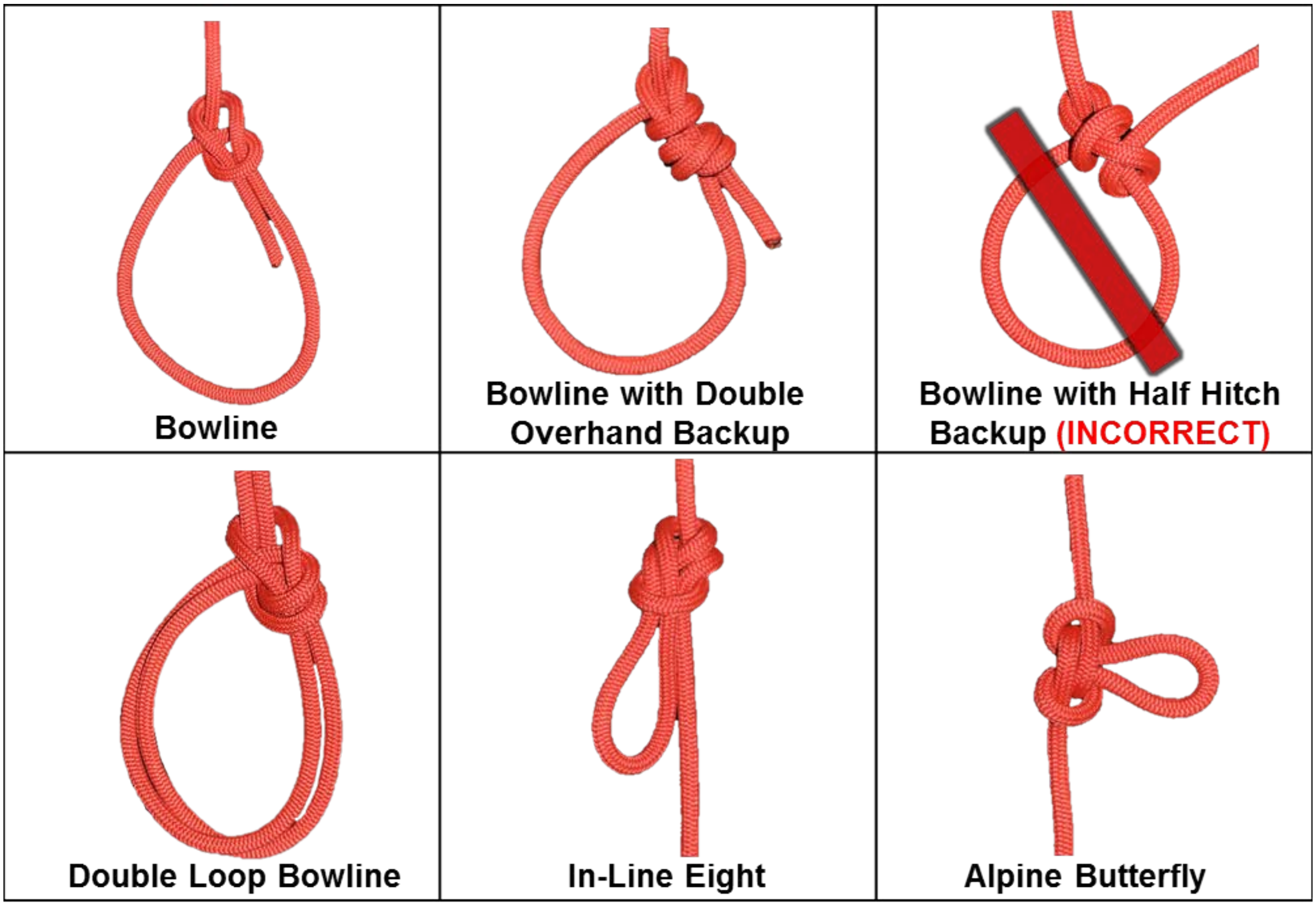

Figure 6.3-3 - Bowline and In-Line Knots

Alpine Butterfly

This knot forms a fixed loop in the middle of a rope (Figure 6.3-3). This in-line knot can be tied in the middle of a rope without access to either of the ropes ends. It handles multi-directional loading well and has a symmetrical shape which makes it easy to inspect. It is useful for anchor rigging, glacial travel applications and for isolating a damaged section of rope.

Frost Knot on a Bight

This knot (Figure 6.3-4) is useful to adjust the location of a focal point when there is more rope or cordage than needed and tying a standard finish knot would place the focal point too far from the anchor. This adjustment is made by increasing or decreasing the amount of tail length coming out of the knot.

Double Overhand Bend aka Double Fisherman's Bend

The double overhand bend (Figure 6.3-5) is a bend used to join two lengths of rope. It is formed by tying two double overhand knots, with each one wrapped around the opposite line.

Figure 6.3-4 Overhand Frost Knot on a Bight

Ring bend (Figure 6.3-7; aka water knot) is frequently used for joining two ends of webbing together. It is tied by forming an overhand knot in one end and then following it with the other end, feeding in the opposite direction. The knot should be "set" by tightening it prior to use. Some teams are using a flat overhand knot for this same purpose.

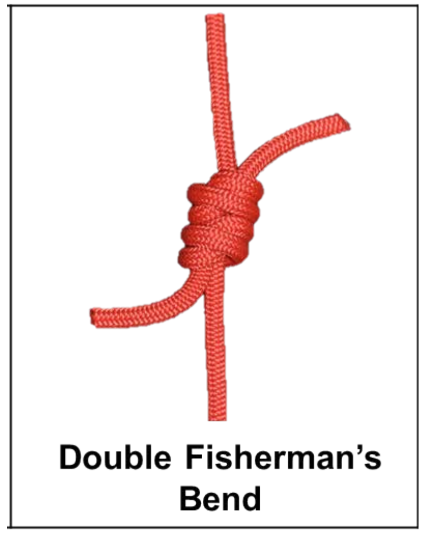

Figure 6.3-5 - Double Fisherman's Bend

HITCHES

Prusik hitch (triple wrap or asymmetrical)

The hitch is formed by applying it to a host rope. **Note: To ensure that Prusik cord moves and grips properly, the diameter relationship between the working part and the Prusik cord diameter must be correct. Generally this is 8 mm Prusik on 11 mm rope, or a 60-80% ratio of Prusik to host rope diameter.** [24] Prusiks should be constructed from Prusik specific cordage that is supple. This is verified using the pinch test — when pinched the bend should be less than half the diameter of the cord. Or, rescuers may want to utilize a purpose-built Prusik like the Bluewater VT Prusik.

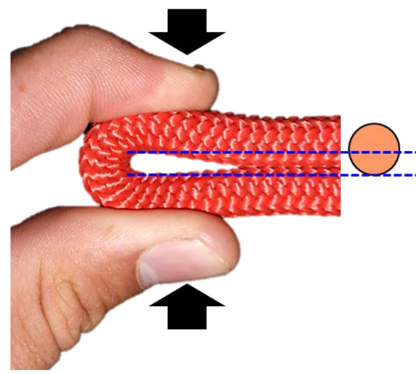

Figure 6.3-6 - Pinch Test

Clove Hitch

A clove hitch (Figure 6.3-7) is two successive half hitches around an object. This knot is particularly useful where the length of the load side needs to be adjustable, since feeding in rope from either direction will loosen the knot to be tightened at a new position.

Girth Hitch

The girth hitch (Figure 6.3-7) is a tie used to attach a rope to an object, which is comprised of a pair of half hitches tied in opposing directions, as compared to the Clove Hitch in which the half hitches are tied in the same direction.

VT Prusik

The VT Prusik (VT=Valdotain Tresse) (Figure 6.3-8) has become a common hitch used as a rappel backup. A notable feature is that it can be released under tension. Tying this hitch requires three spiral wraps followed by crisscrossing the remainder of the cord until all the material is consumed then secure the two sewn eyes with a carabiner. The distel hitch is similar and works well in the same application.

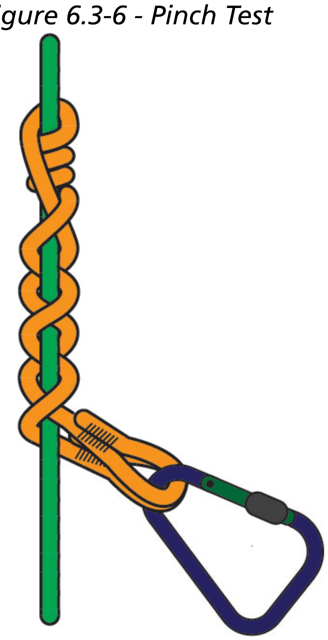

Figure 6.3-8 – VT Prusik

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[24] http://www.sterlingrope.com/product/457056/SC080/_/8mm_Sewn_Cord

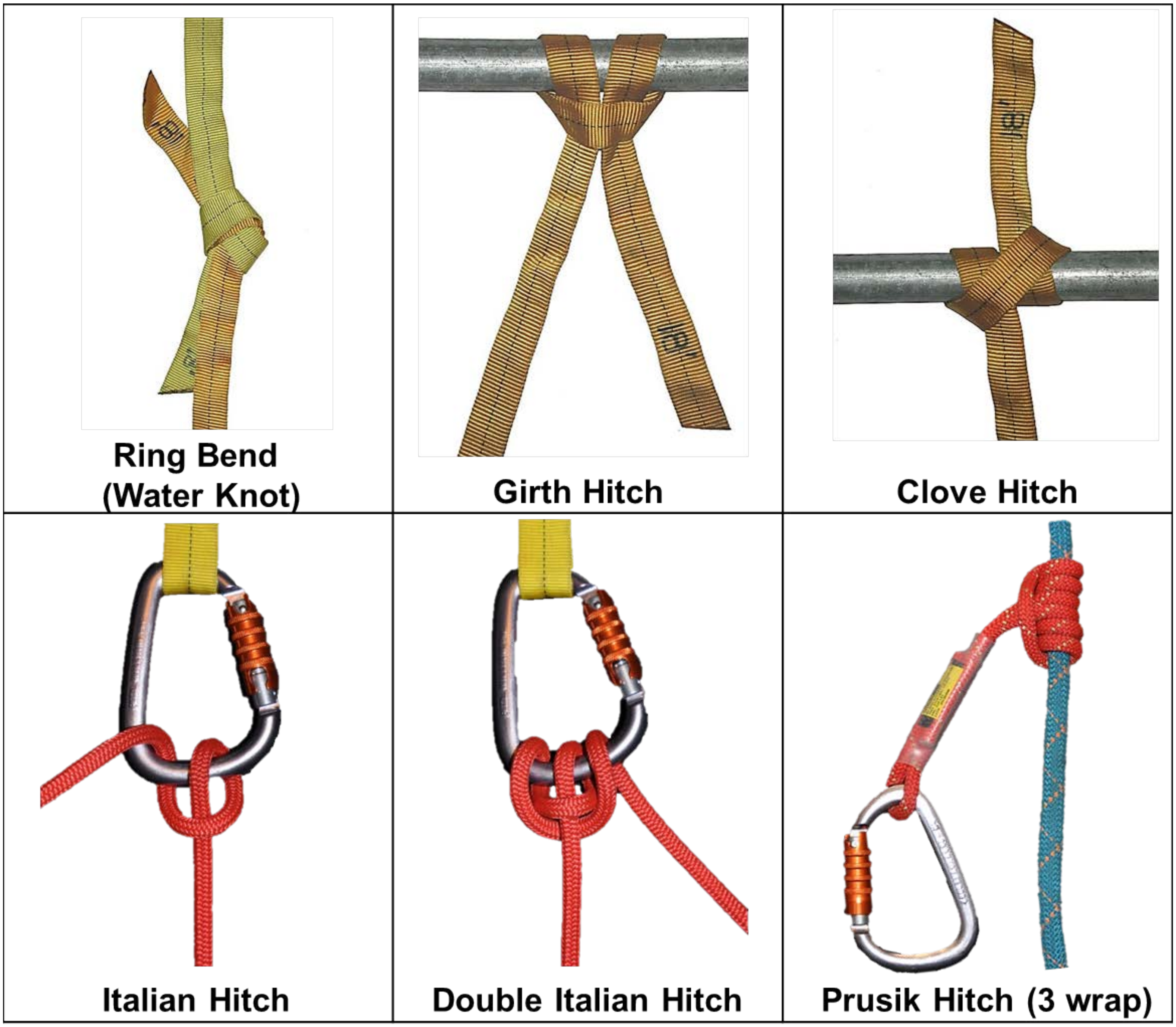


Figure 6.3-7 - Ring Bend, Girth Hitch, Clove Hitch, Italian Hitch, Double Italian Hitch and Prusik Hitch.

Trucker's Hitch

The Trucker's hitch provides an excellent means of binding a load by employing mechanical advantage when tightening down the hitch. It is best constructed with a fixed loop in the line, such as an In-Line Figure Eight or Butterfly. This will prevent a loop from collapsing when cinching down on the load. Once tightened it is secured with a half-hitch overhand tie-off (Figure 6.3-9).

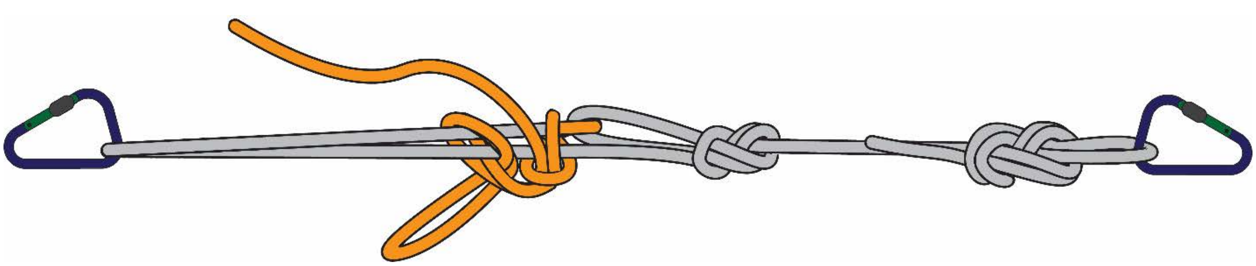


Figure 6.3-9 - Trucker's Hitch

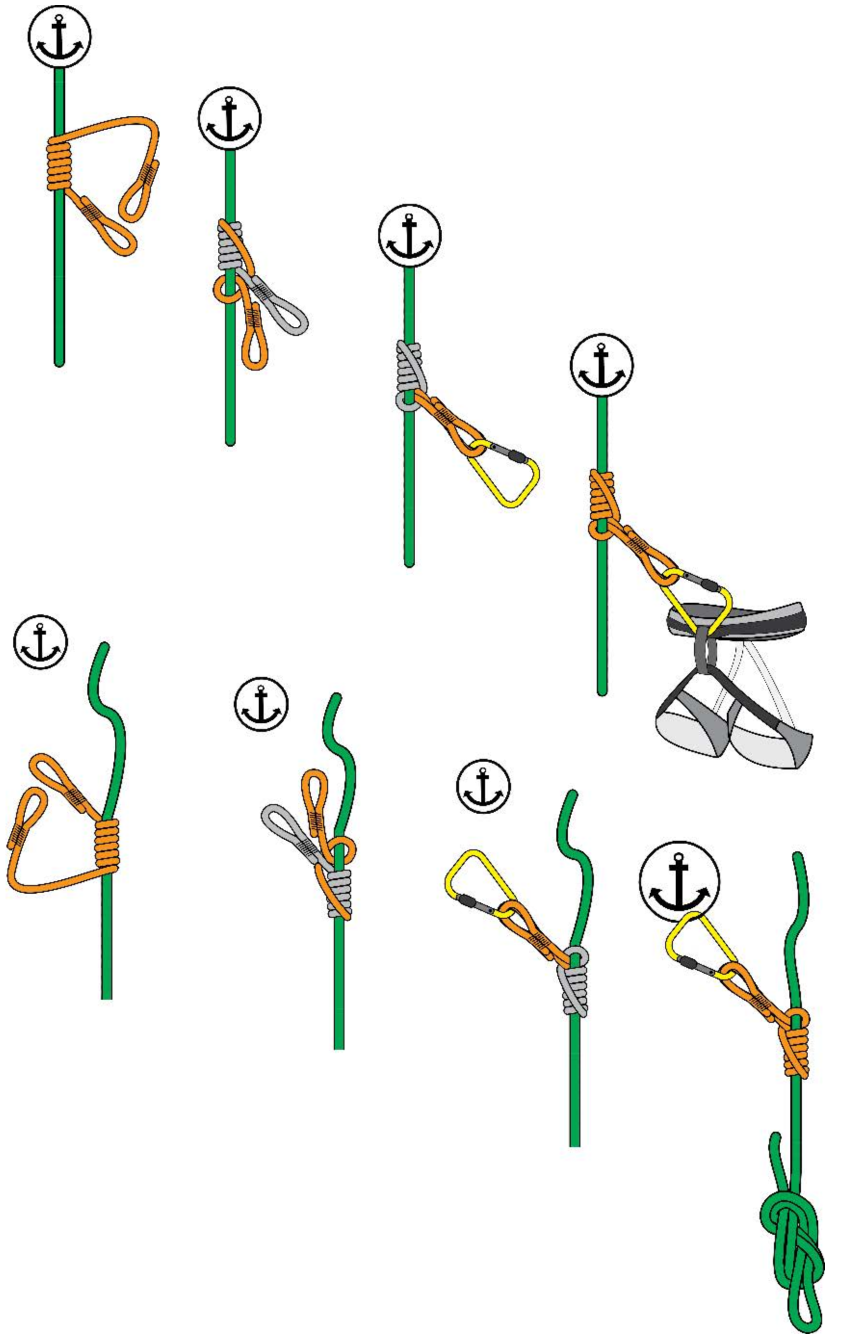


Figure 6.3-10- Schwabisch Hitch, (Max/1)

Schwabisch Hitch

The Schwabisch hitch, aka “asymmetrical ” or “Max/1” (Figure 6.3-10) is tied with the Bluewater VT Prusik and replaces tandem Prusiks as a belay and auto-stop Prusik in rescue systems. Max/1 refers to the method of tying the hitch; one loop of the Prusik is tied on the anchor side, then the remainder of the material is looped around the load side of the rope forming the “maximum” number of loops possible until all the material is consumed. The aramid sheath / nylon core combination of this Prusik is extremely supple. The 6/1 configuration is more easily “broken” in the case of an inadvertent lock-up as compared to a standard triple-wrap Prusik.

Italian Hitch (Münter Hitch, [MB Mezzo Barcaiolo] or Crossing Hitch)
The Italian Hitch (Figure 6.3-11) is commonly used for belaying. This hitch is commonly tied off with a "mule" tie off.

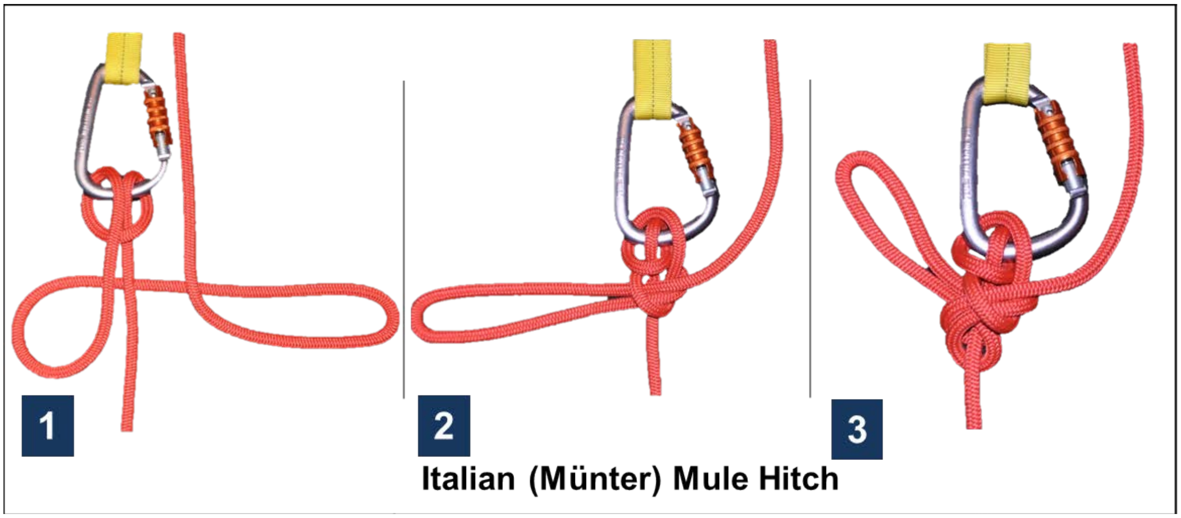


Figure 6.3-11 – Italian Hitch

THE "ITALIAN HITCH" *IT REALLY IS KNOT THE MÜNTER HITCH*

More fittingly referred to as the Italian Hitch, this tie has become inappropriately popularized in the US and Canada as the Münter Hitch. In the late 1950s, three Italian climbers, Mario Bisaccia, Franco Garda and Pietro Gilardoni developed a new belay technique called the "Mezzo Barcaiolo" (MB) meaning; "a half of the knot, which is used by the sailors to secure a boat to a bollard in a harbour." The "MB" was the hitch that Swiss Guide Werner Münter later demonstrated in US mountaineering circles in the 1970s. The Münter name may have unfortunately become commonplace in the US. However, the rest of the world correctly refers to it as the Italian Hitch or MB. *(source: Zanantoni, Carlo. Analysis of Belaying Techniques. UIAA.*

STRENGTH OF KNOTTED ROPE	
No Knot	100%
High Strength Tie-Off (Tensionless Hitch)	100%
Figure Eight on a Bight	77%
Bowline	67%
Double Overhand Bend ("Double Fisherman's")	68%
Ring Bend (Water Knot)	64%

Note: Values will vary with rope type and are based upon static pull testing, not dynamic loading.

STRENGTH OF KNOTS

Knot efficiency is shown relative to reduction in strength.

Field Rule: A knot will reduce rope strength by one-third (33%) and webbing strength by 45%.

7. ANCHOR SYSTEMS

7.1 ANCHOR SYSTEM DEFINITIONS

The ability to efficiently build anchors is a critical rescuer skill. Anchors are the foundation of the entire rescue system. This chapter provides anchor system definitions, safety guidelines, and illustrates several common anchor construction techniques.

ANCHOR SYSTEMS DEFINITIONS

ANCHOR POINT— Single connection point (e.g., tree, boulder, bolt, cam, etc.).

ANCHOR SYSTEM— Multiple anchor points joined into one focal point.

DIRECTIONAL— Rigging technique to change the path of a rope via a pulley attached to a separate anchor.

FOCAL POINT— A location where anchor point rigging is consolidated and focused into a single attachment point for the rescue system. Descent control devices, mechanical advantage systems, and ropes are clipped-in to focal points.

PRE-TENSIONED FRONT/BACK TIES — A pre-tensioned back-tie is rigged to back up an anchor point to add redundancy. A pre-tensioned front tie is rigged to remove slack in the anchor system rigging before putting a load onto the system.

SINGLE PERSON LOAD ANCHOR— An anchor system that is only used for a one-person load. It can usually be built more quickly and with less redundancy since it is being built for one vs. two kilonewtons. This is commonly used for a single rescuer rappelling or ascending, or for edge attendant lines.

RESCUE LOAD ANCHOR— An anchor system built for a 2 kilonewton load. Most anchor rigging will be built to this standard during a rescue.

RESCUE ANCHORS

E - Equalized
A - Angle (Alignment)
R - Redundant
NE - No Extension
S - Strong (Solid)
T - Timely

Figure 7.2-1 EARNEST

7.2 ANCHOR CONSTRUCTION SAFETY

EARNEST— Rescue Anchor Safety Analysis

E - Equalized— Anchor systems should be constructed such that the load is shared among multiple anchor points.

A - Angle/Alignment— In general, check that the interior angle is less than 90 degrees. Make sure anchors are aligned with focal points, the

rope alignment, and the edge transition.
R - Redundant— Anchor systems should consist of multiple anchor points. The exception is that one anchor point may be used if the anchor is so large and solid (Big Friendly Rock BFR or Big Friendly Tree BFT), that its integrity is unquestionable.
NE - No Extension— Anchors should be built so that if one or more of the components fail the remaining components won't extend and be shock loaded.
S - Strong/Solid — Select anchor points that are robust.
T – Timely— Anchor systems should be built quickly. Keep it simple and efficient.

7.3 ANGLES IN ANCHOR SYSTEMS

The interior angle of an anchor system influences the amount of force distributed to the anchor points (Figure 7.3-1). As the interior angle increases, the force distributed to each anchor leg increases. At 120°, the force on each anchor leg is equal to the load. Beyond this point, such as a tensioned highline system or spanned anchor, the force applied to each leg of the anchor surpasses the load being applied.

CRITICAL ANGLES IN ANCHORS

Angle	Total amount of load (force) placed on each anchor leg with a 1 kN load
0°	0.5
90°	0.7
120°	1
150°	~2
170°	**5.7**

GENERAL ANCHOR RIGGING RULE
Construct anchors with an interior angle of less than 90°.

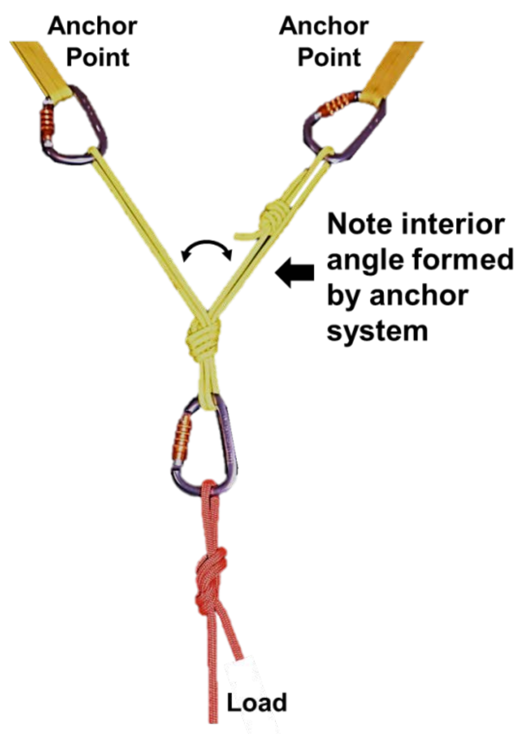


Figure 7.3-1 - Critical interior angles associated with anchor rigging.

7.4 ANCHOR POINTS

There are two main categories of anchor points: natural and artificial.

NATURAL ANCHORS

- Trees: Assess if they are alive/green? Is the tree dead or are the roots exposed? Generally, choose live trees greater than 6” in diameter.
- Rocks: Choose rocks that are large and stationary. Assess if the rock will crumble with pressure or move when force is applied. Ensure the rope can’t pop off, and pad sharp edges.

ARTIFICIAL ANCHORS

- Bolts: Require training and experience to safely place. They should not spin or move. The hanger should be in line with the direction of pull. Use 2-3 bolts per anchor system. Clip a carabiner through the bolt hanger, don't thread the rope through the hanger. Bolts are often joined using a cordelette (10 m of 8 mm accessory cord) to make a "load sharing" anchor.

- Rock Protection (cams, stoppers, pitons): Require training and experience to safely place. Minimum four per rescue anchor.
- Vehicles: Use tow hooks, frame, wheel, or axle. Watch for sharp edges and hot spots. Protect from someone moving the vehicle.

Figure 7.4-1 Bowline

Figure 7.4-2 Bolts and cordelette tied with a figure eight frost on a bight knot.

Figure 7.4-3 Bowline

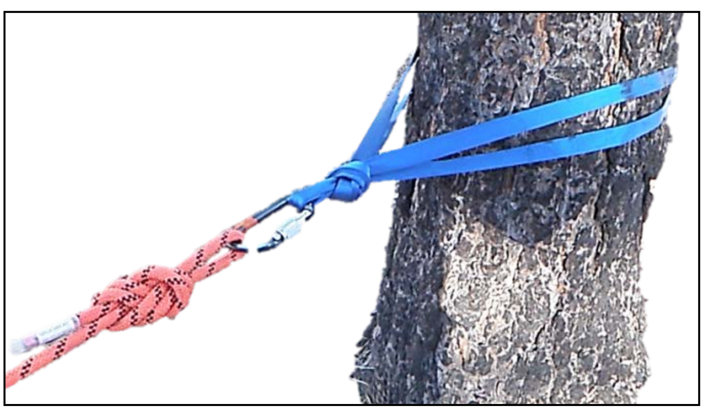


Figure 7.4-4 Basket Hitch

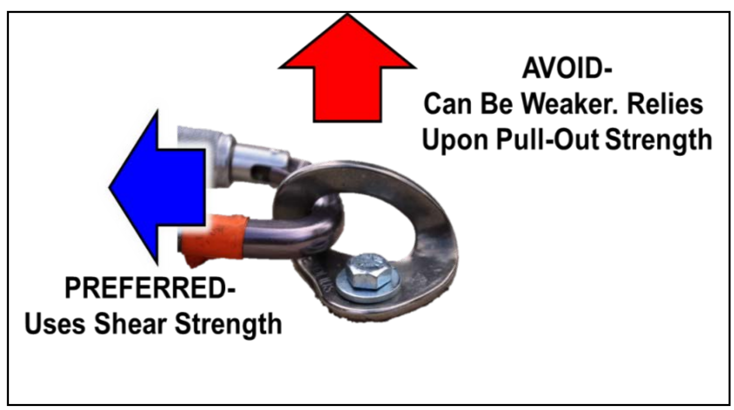


Figure 7.4-5 - Expansion bolts utilize shear strength when a force is applied at a right angle to the placement.

Figure 7.4-6 Wrap 2 pull 1

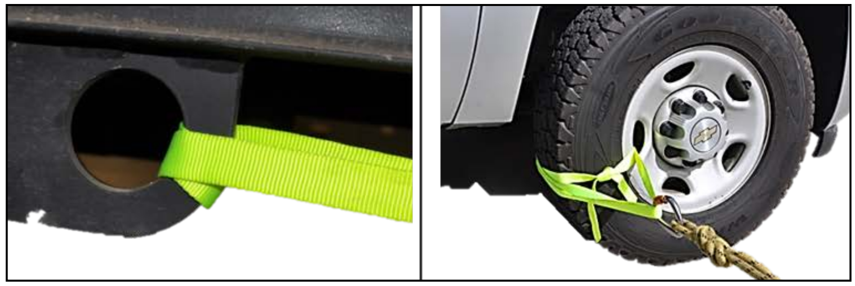


Figure 7.4-7 – Vehicle anchor points

7.5 ANCHOR SYSTEMS

This section will outline some general anchor system principals and show examples. Figure 7.5-1 shows an anchor system overview. Not all anchors will look exactly like this but there are several general principles to note:

Start at the edge transition. The rope alignment (dashed line in Figure 7.5-1) will be 90° to the edge from this location. Rig the focal points close together on the rope alignment far enough back from the edge to allow for rigging and throw distance. Throw distance is the space between the edge and the focal points that is utilized for the haul system.

Choose anchor points on either side of the rope alignment, then bring them together using anchor material to "fix" the focal point along the intended rope alignment. If an anchor only uses anchor points on one side of the rope alignment the system will "pendulum" that direction when weighted.

One-Rope Anchor

The "one-rope anchor" is an efficient way to rig an anchor system. It works well with natural anchors — rocks and trees. The only equipment needed is a rope. Start by tying a bowline around one anchor point. Next, run the rope to the intended focal point, and leave a generous bight of slack. Then, run the rope to the other anchor point. If there is a lot of rope left over, tie a bowline on a bight and leave the rest of the remaining rope in the bag. Finally, to finish, tie a Frost knot 8 or overhand and set it at the desired focal point (Figures 7.5-2 and 7.5-3).

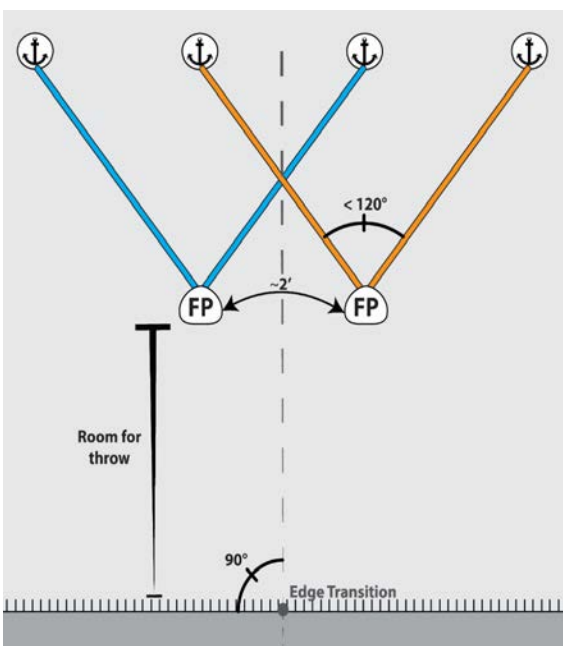


Figure 7.5-1 – Anchor System Overview

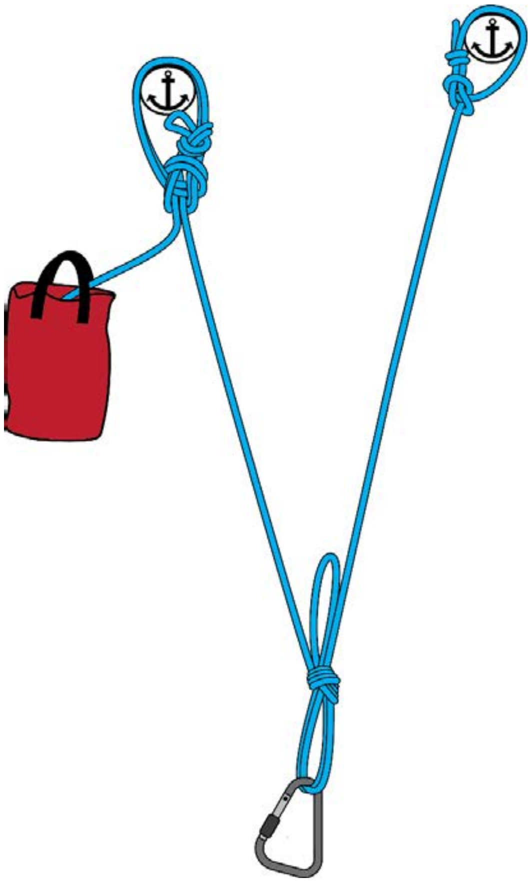


Figure 7.5-2 - One-rope anchor diagram.

Figure 7.5-3 – Side by side one-rope anchors constructed with 11 mm anchor ropes.

W Anchor

This anchor technique is useful when there are three anchor points with the middle point on the rope alignment. This can be constructed using natural or artificial anchor points or a mix (Figures 7.5-4 and 7.5-5).

Figure 7.5-4 – W anchor on trees constructed with 11 mm anchor rope.

Figure 7.5-5 – W anchor on bolts constructed with 8 mm cordelette.

Cordelette Anchor

Cordelettes are a common anchor construction technique for joining rock protection, bolts, pitons, small trees, and other anchor points together. Also called "load sharing" anchors, cordelettes join together multiple anchor points to a single focal point (Figure 7.5-7).

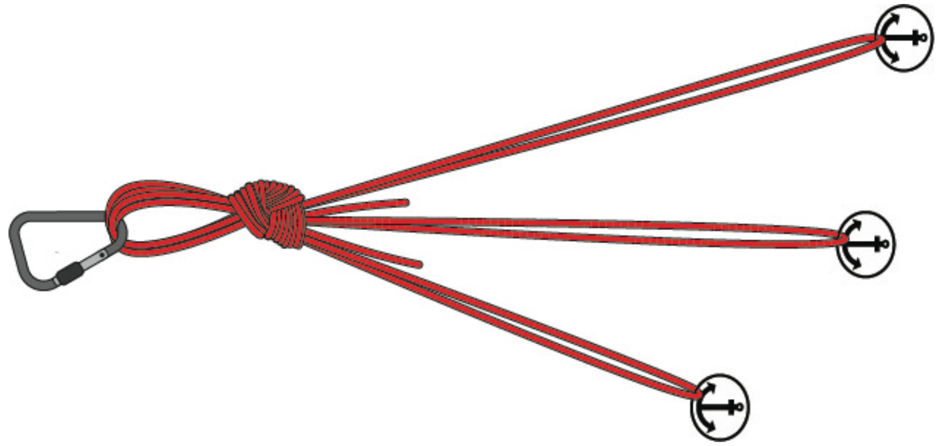


Figure 7.5-6 – Cordelette Anchor.

Figure 7.5-7 Side by side cordellette anchors constructed with 8 mm cordelettes each utilizing four rock protection anchor points.

Quad Anchor

Quad Anchors are often constructed on two side by side bolts using a 240 cm sewn sling. Double the sling so there are four equal length strands. Tie an overhand knot about 6 inches from each end. This leaves four strands of material between the two overhand knots. Clip the two end loops; one into one bolt, the other into the other bolt. Connect to the focal point of this anchor by clipping a locking carabiner into two of the four strands between the overhands (Figure 7.5-8).

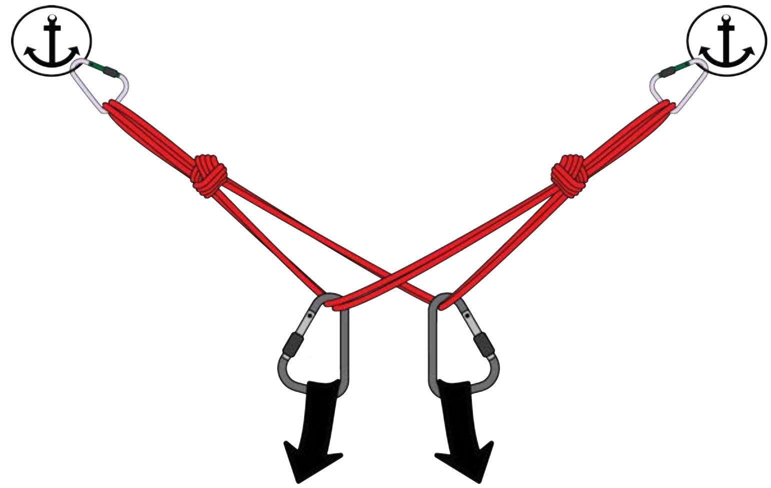


Figure 7.5-8 – Ouad anchor

Vehicle Anchor

Vehicles are useful anchors when the scene is accessible. Tow hooks can be ideal anchor points, but wheels and frame may be used. Avoid sharp edges and hot spots on the vehicle which could melt or damage rigging materials. A vehicle can be placed to function as a directional anchor when throw is needed in tight working quarters such as in diagram 7.5-9. Make sure vehicles are in park, with the parking brake on, wheels chocked, keys secured, and ensure no one will inadvertently drive off in a vehicle being used as an anchor (Figure 7.5-9).

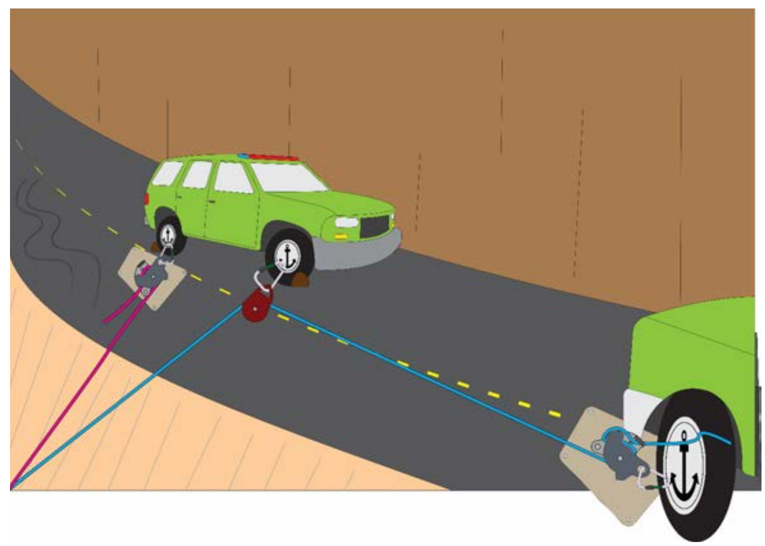


Figure 7.5-9 Vehicle anchor with a directional off another vehicle.

Spanned Anchor

Spanned anchors are an efficient way to rig an anchor system, but they present more risk than other types of anchors. The anchor points in a spanned anchor system MUST be unquestionably solid, such as two large, well rooted trees. Care MUST be taken to avoid all sharp edges. Spanned anchors require a skill and risk assessment level similar to rigging highlines. Do NOT attempt without proper training.

The advantages of spanned anchors are they are quick to rig, use minimal material, and allow adjustability of the focal points. They also provide a rigging option when anchor points are not available for other systems.

Spanned anchors are an advanced technique requiring competent instruction and supervision. Do NOT attempt without proper training.

To tie, take a rope and find the midpoint. Tie this around one anchor point using a bowline on a bight with a double overhand backup. Pull the rope hand tight (one-person) around the other anchor point then secure with two half hitches and an overhand. The two focal points are created using 8 mm triple wrap autoblocks.

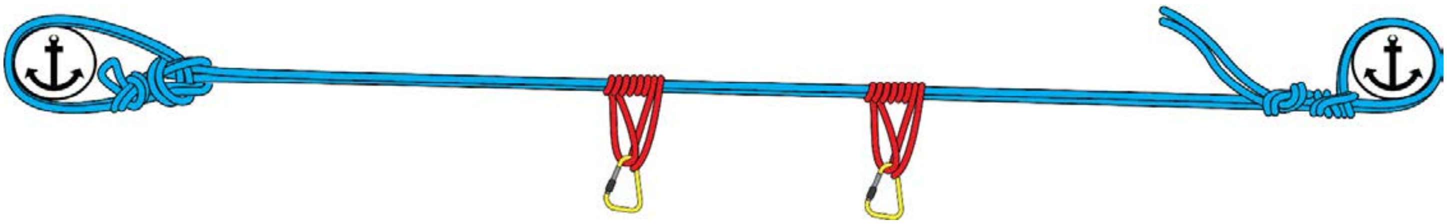


Figure 7.5-10 – Spanned anchor.

The diagram above (Figure 7.5-10) shows the spanned anchor when it is first rigged; hand tight at 180°. Once a load is applied the anchor will flex into an open V shape. The interior angle created when the spanned anchor is loaded should not exceed 150°. Do not over-tighten the spanned anchor when initially rigging.

One concern with spanned anchors is that they exceed the 90-degree interior angle guideline; the "A" in "EARNEST". The skill level necessary to use this technique is similar to the skill needed to rig and evaluate highlines. The anchor points involved must be unquestionably strong, and care should be taken to avoid a "worst case" scenario of BCDTM type drop (2 kN load falling 1 m on 3 m of rope). Advanced instruction and oversight is required.

Pre-Tensioned Back-Tie

Pre-tensioned back-ties are used to add redundancy to an anchor (Figure 7.5-11). Note that the webbing interlocks around the forward tree, creating a linked system.

The alignment of the front and rear anchor points need to be within 15° either side of in-line to the fall line (30° total width) (Figure 7.5-12).

Two pretensioned back-ties can be constructed with a single rope if the distances are not too great, by starting at the focal point and splitting the rope to use half the line rearward on each back-tie.

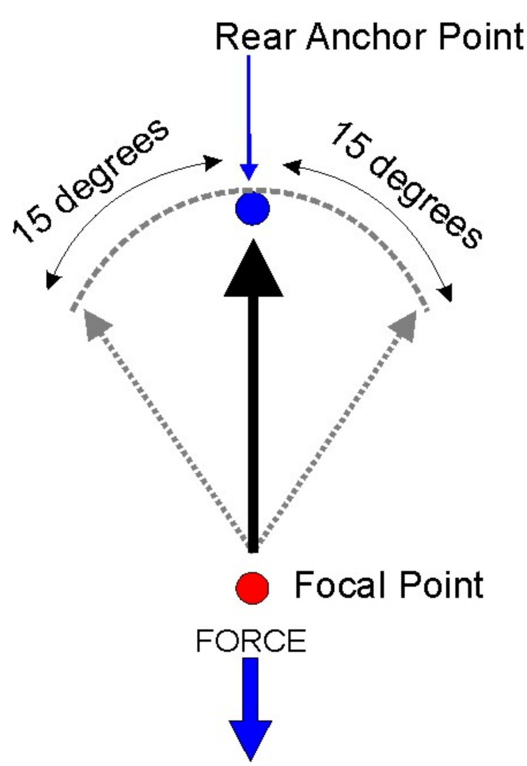


Figure 7.5-12 – Back-tie fall line angles.

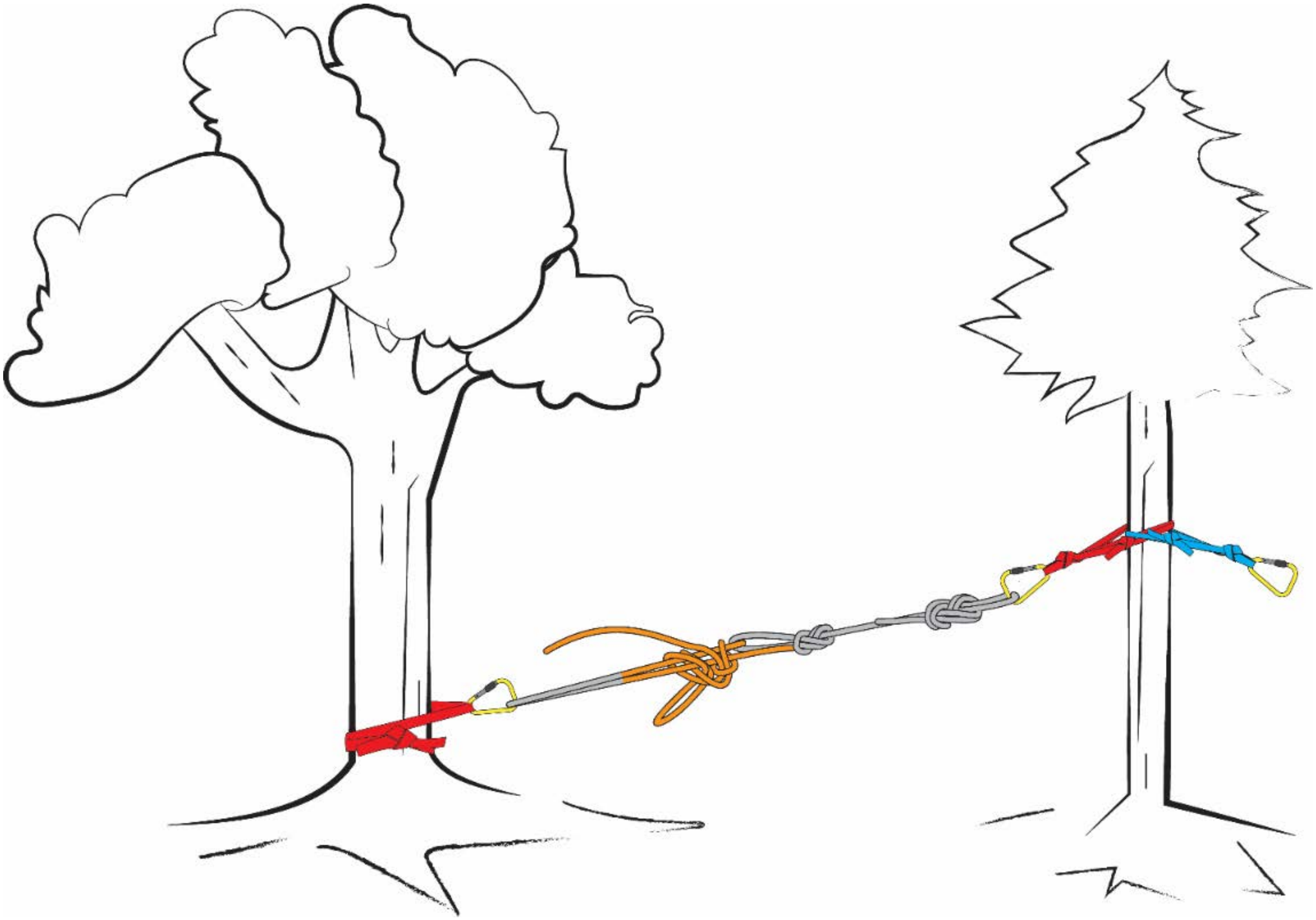


Figure 7.5-11 - Pre-tensioned back-tie constructed with a trucker's hitch.

Directionals

Directionals provide a means of redirecting the path of a rope under tension. This may be necessary due to terrain, vegetation, and anchor availability constraints.

Figure 7.5-13 - Directional pulley with jigger as adjustable tether.

Constructing a directional with a tether that is adjustable by means of a jigger or adjustable hitch allows greater flexibility, permitting the pulley to be placed in the proper point of alignment (Figure 7.5-13).

Directionals can multiply forces in the system. For example, if the two mainlines run through a 90 degree directional, the force on the anchor of that directional will be 1.4 x the load. This is acceptable, but should be noted when selecting anchors and evaluating rigging.

Picket Anchor

Picket anchors can be used in sandy terrain where no other anchors are available (Figure 7.5-1

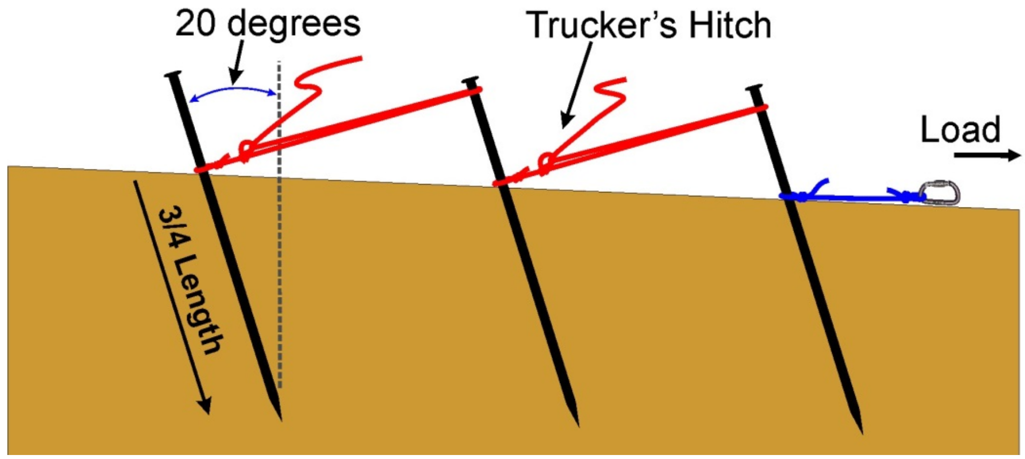


Figure 7.5-14 - Picket system using trucker's hitch for tensioning between stakes.

8. RAPPELLING AND ASCENDING

8.1 INTRODUCTION

Rappelling and ascending are skills every SAR team member should have. These skills enable rescuers to access patients quickly as well as self-extricate, if necessary.

In training, generally two ropes are used for rappelling and ascending (fixed line and belay line). But in real life, rappelling and ascending are often accomplished using single rope technique (SRT). SRT involves reliance on only one rope to support the load. It is inherently more risky than two rope techniques. During SRT the rescuer should attach to the rope with two points of contact to provide redundancy. The primary attachment point is the descent control device (DCD) or ascenders. The second point of attachment is a “third hand” or “auto-stop” device or hitch when rappelling, and an auto stop device or “tying in short” when ascending. When using SRT, special care must be taken to protect the rope from sharp edges and rockfall.

8.2 RAPPELLING

Rappelling, also referred to as “rapping” or the European “abseiling” (from the German word abseilen, meaning "to rope down"), is the controlled descent down steep terrain using a fixed rope (Figure 8.2-1). The original body rappel, known as the “Dulfersitz," ran the rope around the rappeller’s body for friction. Modern rappelling techniques employ a descender or friction device. This permits a rescuer to quickly access injured or stranded subjects in technical terrain.

Figure 8.2-1 A rescuer rappels into a canyon.

It is important to understand that **RAPPELLING IS DANGEROUS**. Rappelling accidents resulting in injury or death are frighteningly common. Complacency is a common reason for these accidents.

The following are important safety considerations relating to rappelling:

- Verify the rope reaches the target.

- Double check your harness, carabiners, and all rigging prior to going over the edge.
- Check that carabiners are locked and not cross loaded.
- Use a **buddy check system** to have your rigging inspected by other rescuers.
- Employ an auto-stop hitch (autoblock, VT Prusik, etc.) as a backup.
- Keep the brake hand below the descending device— NEVER LET GO!
- Keep hair and clothing away from the descending device.
- Carry a cutting tool and a backup Prusik for emergencies.
- Avoid dislodging rocks with the rope.
- Do not bounce during a rappel — this can shock the rappel anchor.
- Descend slowly and avoid excessive heat buildup.
- Use well-fitting gloves when rappelling.

HASTY RESCUE ANCHOR

The hasty rescue anchor can be rapidly constructed using one rope. Locate two in-line anchor points in the fall line of the rappel. Tie a bowline around the furthest anchor point and rig forward capturing three wraps of the rope around the anchor point closer to the cliff edge (Figure 8.2-2).

An even faster option, if there is a "big friendly tree" available, is to simply tie a bowline around that single point and rappel off it. Be aware that there is no redundancy if you are going to do this and the anchor needs to be solid.

Figure 8.2-2 Hasty Rescue Anchor

RAPPEL DEVICES

There are many devices on the market for rappelling. Two commonly used devices are the Black Diamond ATC Guide, and Petzl Grigri. Rescuers should also know the Italian hitch as a backup option in case a rappel device is lost or dropped. The Italian hitch is not recommended as a primary decent control method because it twists the rope.

RAPPEL BACKUP ("THIRD HAND")

Rescuers should employ a backup when rappelling. This is normally accomplished with an auto-stop friction hitch. This backup hitch, if tied correctly, will secure the rescuer if something happens and they are unable to manage the rappel.

The backup hitch is also beneficial if the rescuer needs to go hands free to clean debris, place edge pro, etc. Simply set the hitch, make sure it is holding, and then go hands off the rope. For additional security, a backup knot can be tied when going hands free. There are two common methods for rigging a rappel backup. 1. Hitch below the DCD, or 2. Hitch above the DCD.

Figure 8.2-3 An ATC is extended with a blue Dyneema sling. An autoblock friction hitch is also attached to the belay loop and tied on the untensioned rope, below the ATC.

1. HITCH BELOW THE DCD

In this method, girth hitch a sling through the waist and leg loops of the harness. A 60 cm single-length sling is about the right length (length can be adjusted by tying an overhand knot in the sling as well). Attach a DCD to the rope and clip it to the end of the sling. Then, tie a triple wrap Prusik hitch or autoblock hitch to the rope below the DCD and clip this to the belay loop. Make sure the hitch material is the correct size for the rope you are tying it to and that it meets safety/strength requirements. Also ensure that the DCD cannot "mind" the Prusik and prevent it from actuating.

Be aware that by extending the rappel device you may be making an edge transition more difficult especially if it is an overhanging edge. Know your terrain and scout your edges before committing to make sure you are set up correctly for the rappel.

2. HITCH ABOVE THE DCD

The other method for creating a rappel backup is to tie a hitch above the DCD. There are specific hitches that should used in this application that can be released when under tension. Do not use an auto-block or triple wrap Prusik as they are extremely difficult to unweight once locked up.   Two hitches commonly used for the "hitch above the DCD" application are the Valdotain Tresse and the Distel hitch. These are tied with a commercially sewn open-end Prusik like the Bluewater VT Prusik. This is available in 7 mm and 8 mm diameter. 7 mm is acceptable for single-person loads. 8 mm should be used for rescue load applications.

Both the Valdotain Tresse and Distel hitch are directional hitches; meaning, they must be tied in the proper direction relative to the load and tension or they will not catch. If weighted, both are easy to break making either a good choice if the rescuer is anticipating needing to go "hands free" during the rappel.

NOTE: It is important to understand that the number of wraps and crosses required for optimal performance will vary with rope size, type and condition.

Figure 8.2-4 — VT Prusik as auto-stop for rappelling. In this configuration it can be tended and released easily.

8.3 ASCENDING

Figure 8.3-1— Rescuer uses mechanical ascenders on a fixed line with a separate belay in place.

Various techniques exist for ascending a fixed rope. Depending on the situation, some are more efficient than others. It is best to learn one ascending technique well and feel confident in its use, yet still be familiar with some alternate methods.

There are many types of ascenders available, but these are the most common:

- Handled Ascenders
- Friction Hitches (Purcell Prusik System)

An **ascender** is a mechanical device used for climbing a rope (Figure 8.3-1). Handled ascenders have the advantage of being easily attached or removed from a rope. The safety catch on a mechanical ascender will normally keep it from twisting off of the rope in a vertical orientation, however additional caution needs to be exercised during use on a horizontal traverse. Depending upon the ascender design, it can be kept parallel to the rope during a traverse by attaching a carabiner through the handle or the nose of the ascender and around the fixed rope, which will reduce the likelihood of the ascender becoming detached (Figure 8.3-2).

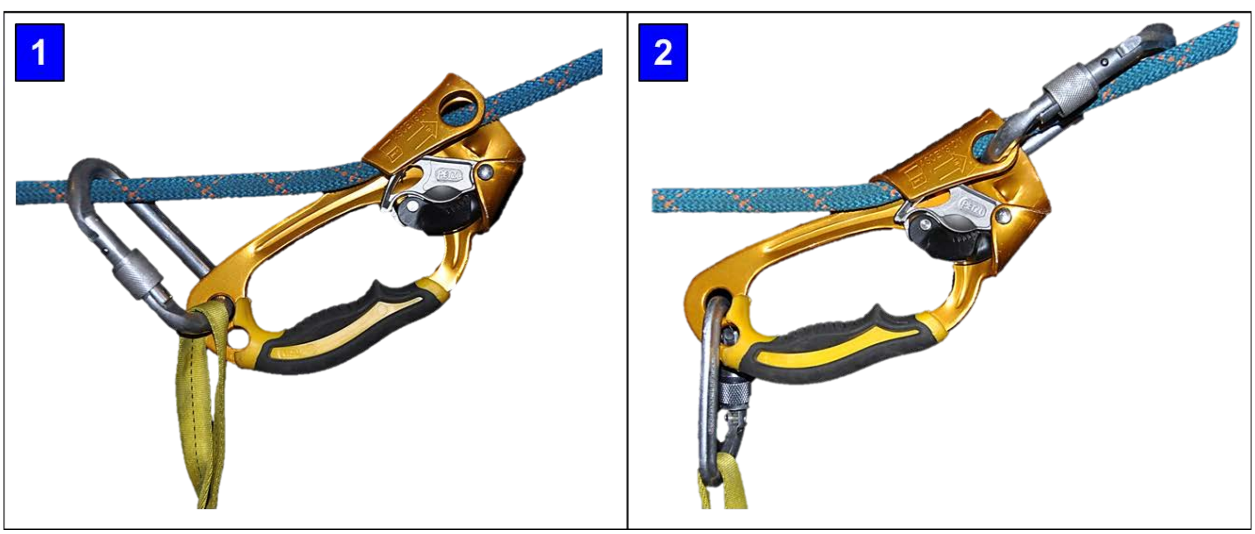


Figure 8.3-2 — Providing for security during a horizontal traverse with ascenders. Petzl Ascension Ascender shown rigged for traversing a fixed rope with; 1. Carabiner clipped to fixed rope from ascender handle. 2. Carabiner clipped through ascender nose and around the fixed rope (Note: Both techniques are recommended by the manufacturer).

TWO POINTS OF CONTACT— Ascending Systems[25]

An ascending system should have **"two points of contact at or above the waist"** with the rope for redundancy. A set of ascending devices, both attached to the harness, count as one attachment point. The second point may be a:

- Separate top belay.
- Prusik: Attach the Prusik to the rope above the lower ascender. Make sure it is also connected to the belay loop of the rescuer. As long as the rescuer has not weighted the Prusik, it should be minded by the lower ascender as it is slid up the rope.
- Device: There are several devices in use for this purpose such as the Petzl Grigri and Petzl microcender. Attach to the belay loop of the seat harness in the correct orientation to self-actuate. The rescuer may have to pull slack through the device until there is enough rope weight below for it to auto feed.
- Tying in short: Periodically tie a bight in the fixed rope immediately below the rescuer and clip into the climbing harness with a locking carabiner. A figure-8 or alpine butterfly are good knot options for tying in short. Remember, the longer the rescuer goes between tying-in short, the longer the fall and the higher the potential

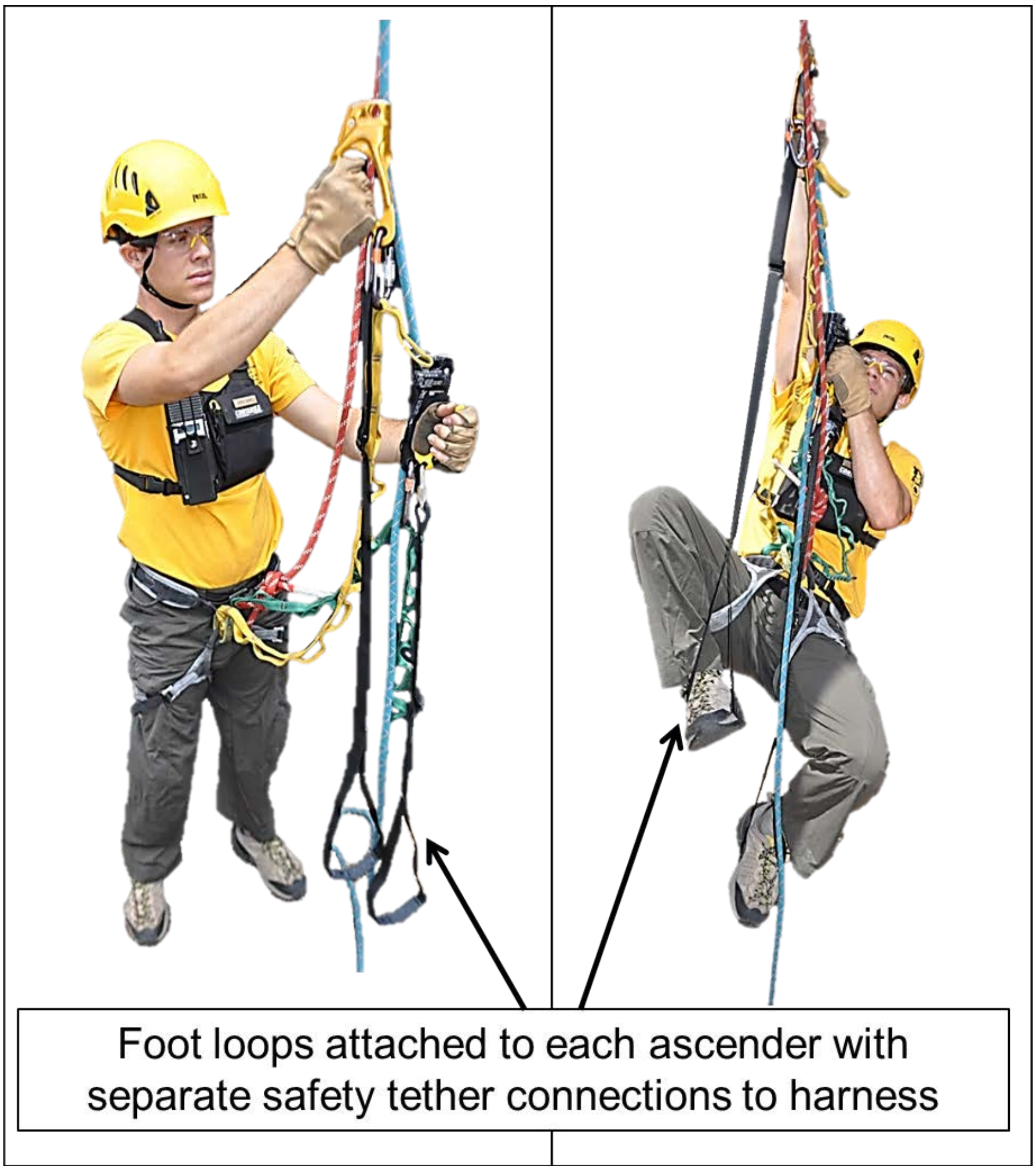


Figure 8.3-3 - Yosemite Ascending System.

[25] Smith, Bruce. Personal interview. May 5, 2015.

Figure 8.3-4 Texas Ascending System.

consequences. The rescuer will also have a loop below them that will potentially need to be managed (terrain-dependent).

SAFE ASCENDING SYSTEM[26]

The critical criteria that all vertical ascending systems should meet:

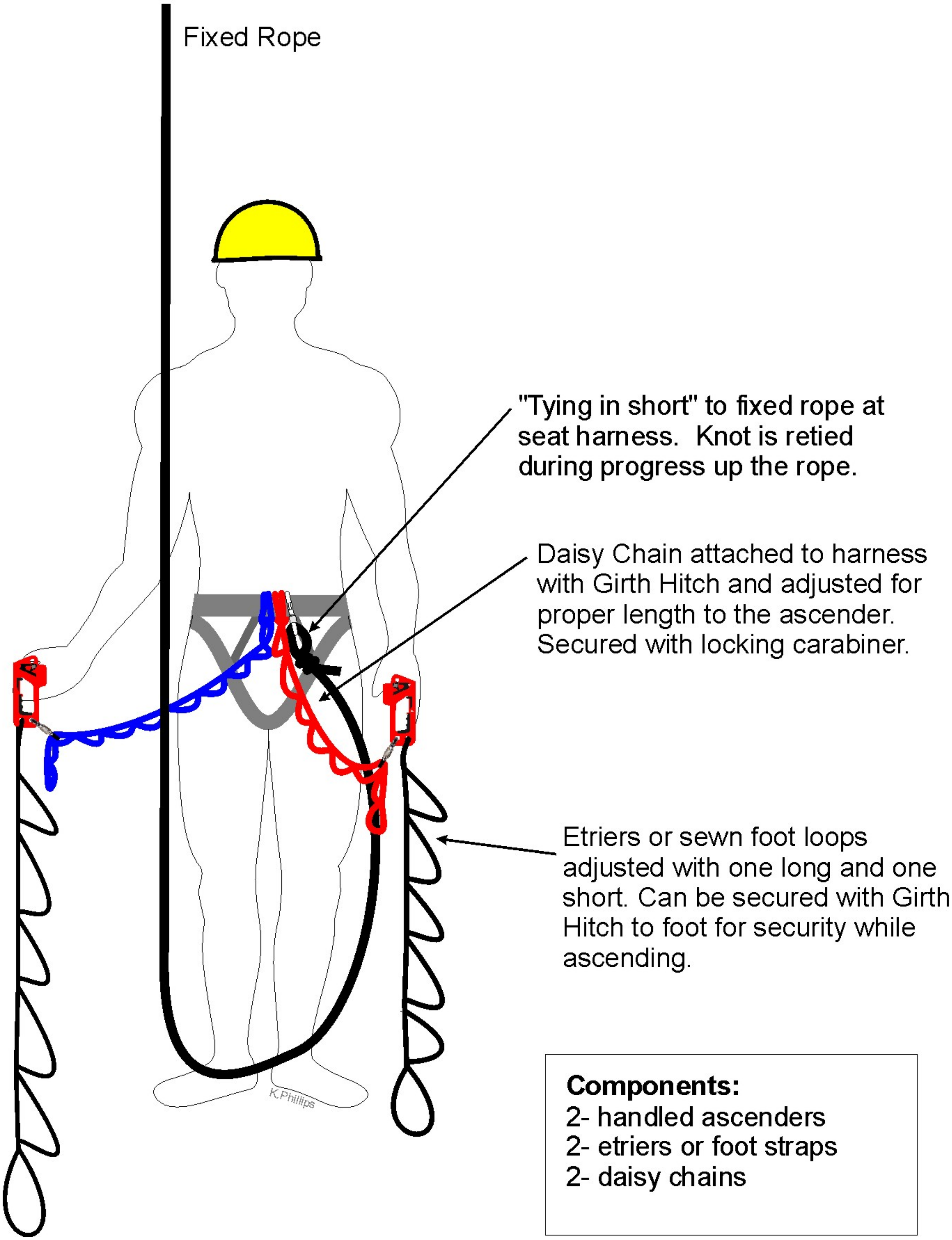
1. If any component fails the climber will not fall upside down or to the ground.
2. If there is a failure, there should be a third ready-to-use ascender or quick attachment system (QAS) that can be placed into service.
3. A climbing system should have two points of contact on the rope at all times.
4. A regular system of inspection and replacement of worn components.

YOSEMITE ASCENDING SYSTEM

The Yosemite Ascending System was developed as an efficient ascending technique for "big wall" climbing. The simple method employs two handled ascenders, two foot loops (etriers) and two daisy chains (Figures 8.3-3 and 8.3-5). It does not require the use of a chest harness. Right-handed users should place their right ascender in the higher position and vice versa for left-handed users. Each ascender is attached to the seat harness by means of a separate sewn daisy chain. Attach the end of each daisy chain directly to the seat harness with a girth hitch to ensure a reliable attachment rather than using a locking carabiner for this connection. The other end of the daisy chain is attached to each ascender with a dedicated locking carabiner. The measurement of the daisy chains and etriers is critical and worth adjusting until they are at the most efficient length. The daisy chain to the upper ascender should be less than a full arm extension. It is important the length of the etriers also be adjusted for personal comfort. Initially getting off the ground may require "thumbing"-using your thumb to open the cam on the lower ascender, otherwise lifting the ascender upward will not cause the rope to slide through the ascender.

[26] National Speleological Society, Basic Vertical Training Student Manual. pg. 17.

Yosemite Ascending System
(Big Wall System)



Components:
2- handled ascenders
2- etriers or foot straps
2- daisy chains

Figure 8.3-5— Yosemite Ascending System

Advantages

- Very simple to setup or improvise from team gear during an incident
- Works well in steep angle as well as vertical terrain

Disadvantages

- Requires suitable physical strength

MODIFIED ASCENDING SYSTEM

This ascending system is considered a sit-stand ascending system. As opposed to a ropewalker configuration, which uses independent ascenders to each foot, a sit-stand ascending system uses two ascenders (originally Prusik Hitches) but only one foot loop. The top ascender is attached to the seat harness with a daisy chain or other adjustable attachment. It should be measured just shy of full arm extension — you need to be able to reach the handle when you have sat back and are weighting the system. The lower ascender is also attached to the seat harness via a daisy chain and has an etrier or foot loop attached. The length of the foot loop depends on rescuer preference: The shorter the length the more strength involved to do a full squat stand-up/pull up but the more distance up the rope you will cover with each cycle.

The rope ascending cycle involves extending the top ascender up the rope to full length then "sitting down" on the top ascender. Then raise the lower ascender and foot loop up the rope. This is followed by standing up on the foot loop and moving the top ascender upward. For shorter technical ascents, less fit individuals find a sit-stand system less strenuous. However, there are much more efficient ascending systems in existence.[27]

Advantages

- Simple and easy to set up
- Does not require a chest harness
- Can be employed by less fit individuals

Disadvantages

- Less efficient over long distances

Grigri ASCENDING TECHNIQUE

Another efficient and convenient ascending technique involves the use of a Petzl Grigri belay device in conjunction with a single handled

Figure 8.3-6 - Grigri Ascending Technique

[27] Montgomery, Neil R. Single Rope Techniques. p. 91.

ascender with an attached foot loop. The Grigri is attached to the rescuer's harness and an additional harness attachment is created with an adjustable tether (e.g., sewn daisy chain) that is rigged directly to the handled ascender (Figure 8.3-6). The rescuer stands up on the foot loop and then pulls on the brake hand side of the Grigri to progress the device up the rope. Because of the spring-loaded design of the Grigri, the brake hand should be maintained on the rope during progression up the rope.This prevents slippage when the Grigri becomes unweighted. Alternatively, the brake strand coming out of the Grigri can be run through a small pulley on a carabiner clipped to the upper ascender creating a 3:1.

PURCELL PRUSIK ASCENDING SYSTEM

A set of Purcell Prusiks can provide a rescuer with a readily accessible and inexpensive means to ascend a fixed rope. The added functionality of Purcell Prusiks for numerous other tasks such as lanyards makes them essential for every rescuer. The three components of the system include a long foot Prusik, medium foot Prusik and a short harness Prusik (Figure 8.3-7). The two foot Prusiks permit easier movement in non-free hanging terrain (e.g., steep slab of rock). Additionally, if one foot Prusik is being employed as an adjustable lanyard (e.g., litter attendant), then the other foot Prusik can still be used to ascend a short distance, if necessary. **The traditional Purcell Prusik Ascending System does not meet the requirement for two points of attachment above the waist.** This shortcoming can be overcome by incorporating an additional safety tether to the harness from the Foot Prusiks.

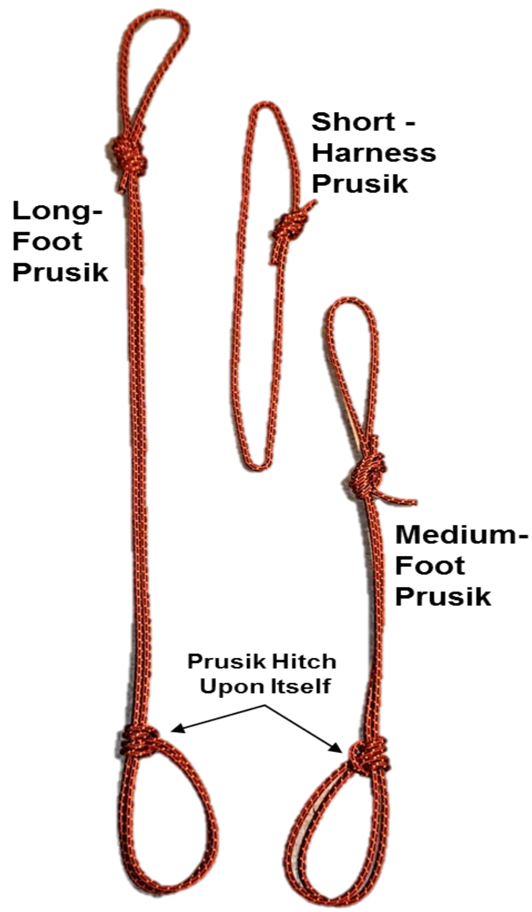


Figure 8.3-7— Set of Purcell Prusiks.

ASCENDING TIPS

If ascending a fixed rope that is rigged with intermediate connection points to the rock or other obstacles, it will require the rescuer to remove the top ascender and replace above the obstacle. The process is then repeated with the lower ascender. Two points of contact can be maintained with the rope, through the use of a QAS or tying in short.

8.4 CHANGEOVERS

Changing over from ascending to rappelling, or vice-versa, while part way up a rope, requires that the rescuer follow a logical sequence of steps to ensure personal safety. Maintain two points of attachment during this changeover process. Always know where the weight/tension is being held. **During a**

changeover do not open any attachment carabiner to the harness while it is supporting a load. Use separate attachment carabiners for ascending and rappelling components.

ASCENDING TO RAPPELING

The steps for conducting an ascending to descending changeover are:

- Position the upper ascender to nearly full extension and place your weight on this ascender.
- Ensure an additional secure attachment (e.g., separate belay, tie in short or QAS).
- Attach DCD and autostop hitch to the fixed rope below the upper ascender.
- Transfer the tension to the DCD and lock off with a secure tie or auto-stop hitch. The rescuer may need to stand up in the foot loop and pull some rope through their DCD to effectively transfer the tension.
- Remove both ascenders.
- If attachment included tying in short, release this connection from harness.
- Release lock off on DCD and initiate rappel.

RAPPELLING TO ASCENDING

The steps for conducting a descending to ascending changeover are:

- Set your autostop hitch or tie-off your rappel device.
- Place your upper ascender as high up on the rope as you can reach.
- Place your lower ascender on the rope below the upper ascender. Make sure both ascenders are girth-hitched into the harness and adjusted appropriately.
- If you are not attached to a top belay, attach your second point of contact (Prusik, Grigri, tie in short) in the appropriate location.
- Stand up in the foot loop and extend the upper ascender. This will unweight the rappel device and transfer the weight onto the ascending system. You may need to pull some slack through the DCD to free it up.
- Sit back onto the system — the weight should be on the upper ascender.
- The rappelling gear should be untensioned. Remove it and any friction hitch.
- Move the lower ascender up the rope and pull any slack rope through the second point of attachment if applicable.
- Ascend.

8.5 TOP BELAYS

For increased safety over SRT, teams may elect to belay the person rappelling or ascending on a separate belay line. This belay line is attached to the rappeller's seat harness via a figure-8 follow-thru or a bowline. Note that when employing this technique, all of the rescuer's weight should be on the fixed line. The belay should be "hand-tight" only.

Figure 8.5-1 Rescuer tied into top belay via harness hard-tie points. (Primary attachment system omitted for clarity)

Figure 8.5-2 Quad anchor fixed line / belay setup.

Belay Line Rigging

Figure 8.5-2 shows one way to set up a fixed line (green rope) / belay line (orange rope) station with a quad anchor. The belay line is rigged with an ATC and VT Prusik in max-over-one configuration. While the rescuer is rappelling, mind the Prusik and let rope slide through the system while always maintaining control of the brake strand.

If the rescuer switches to ascending, pull rope through the system with the top carabiner acting as a pulley. The ATC will mind the Prusik as the rescuer ascends upward and rope is taken in.

9. RESCUE SCENE SIZE-UP

9.1 OVERVIEW

This chapter will explain how to size-up a technical rescue scene. This is typically performed by the technical team leader. The purpose of the size-up is to analyze the rescue situation, determine the appropriate mission profile, and brief the team on the plan. Teams should play to their strengths in whom they select to perform the team lead role. Size-ups require judgement, experience and skill.

Figure 9.1-1 Rangers conduct an 1,800 foot raise of an injured climber at the Black Canyon.

Many technical rescues are performed from the top down: the rescue team travels to the top of the cliff and rescues the subject below. However, some are performed from the ground up, or from the side via lead climbing or other methods. The principles explained in this chapter apply to any technical rescue.

Upon arrival at the scene the team lead designates an area for team gear (ropes, litter, hardware) and a separate area for personal gear (backpacks). The team lead may also designate some team positions at this point so someone can get started rigging a rope to the edge and others can prepare gear. The team lead then performs the scene size-up.

9.2 SCENE SIZE-UP

The team leader has four critical responsibilities to perform during the scene size up: 1. Evaluate the vertical terrain and rescue situation. 2. Evaluate the rigging site. 3. Assess mission profile and develop a plan. 4. Brief the team on the plan.

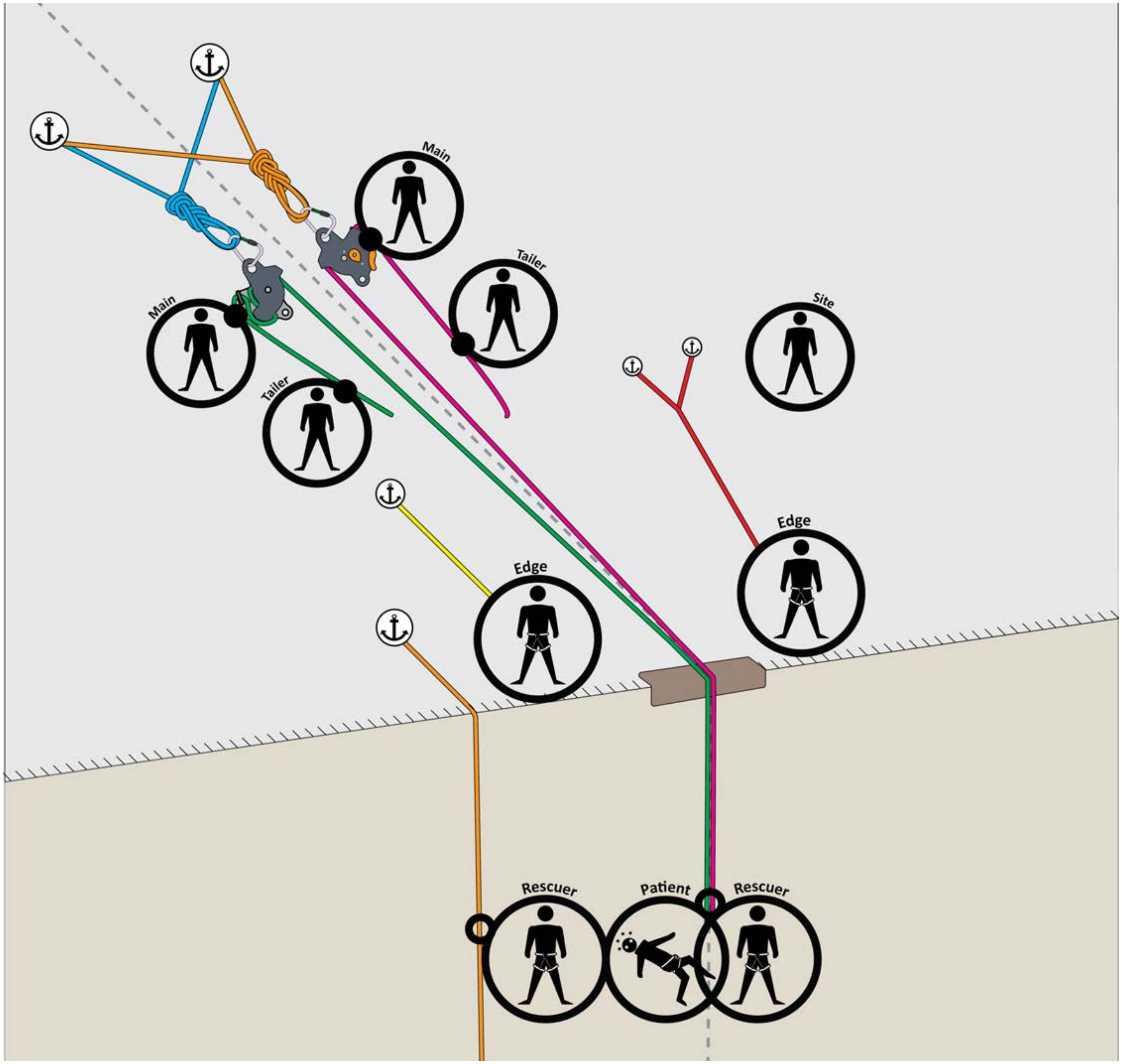


Figure 9.2-1 Overview graphic showing edge transition, rope alignment, focal points, edge attendants, and anchors for a typical rescue scene setup.

1. **Evaluate the vertical terrain and rescue situation.** The team lead (or designee) scouts the vertical terrain and rescue situation and assesses the following:

- Where is the subject (rope length needed, how to access)?
- Subject condition (how secure are they, injuries, are they ambulatory)?
- Type of terrain (vertical, steep angle, ice gulley, talus slope)?
- Should the system be rigged directly above, or to the side of the subject?
- Where is the fall line and will it change due to terrain?
- Where should the edge transition be located?
- What hazards exist (loose rock, sharp edges)?
- Where should the subject go once the rescuer reaches them (raise up, lower down, move across a ledge)?
- What rescue technique is appropriate (pickoff, guiding line, lead climb, short haul)?
- How is the subject going to be evacuated once they get off the vertical terrain (carry out, helicopter, walk) and what pathways/clearings need to be maintained to finish the evacuation process?

2. **Evaluate the rigging site.** Once the vertical terrain has been scouted, the team lead evaluates the rigging site. This process proceeds from the edge back; starting at the desired edge transition location. The team lead assesses numerous factors in this phase including:
   - Is there one edge transition or multiple?
   - Is the edge transition abrupt or rounded?
   - Should a high directional be used or is one available?
   - Where will the rope alignment fall? (perpendicular to edge)
   - What anchors are available?
   - Do constraints such as terrain, vegetation, or availability of anchors necessitate a directional?
   - If a raise is anticipated, is the throw adequate? Is it elevated or will the pulleys be scraping over a convexity?

Figure 9.2-2 YOSAR rigs for a big wall rescue on El Capitan. (NPS photo)

3. **Assess mission profile and develop a plan.** After the team lead has evaluated the vertical terrain, rescue situation, and rigging site they are prepared to determine the mission profile and make a plan. This does not have to occur in a vacuum, the team lead can and should discuss their plan with other

team members as needed.   All of the factors previously discussed influence this plan. There is no one-size fits all response. Each situation is different. The main decision points to consider are:

- What type of rope system to utilize?
- Location of edge transition, rope alignment, and focal points.
- Whether or not a high directional will be used.
- Ensure edges can be padded.
- What will happen when the ropes and focal points are under tension; will they move? If a high directional is being utilized, will the DCD's go out of reach?

4. **Brief the team.** Once the team lead finalizes the plan, brief the team using the Format for Briefing in Emergencies (Chapter 3). In addition to the general briefing about the situation and hazards, the following specific rigging information should be included:
   - Team assignments. Positions typically include:
     - Team lead / control
     - Main line 1
     - Main line 2
     - Edge attendant(s)
     - Litter attendant
   - Explain the general goal of the operation (for example: lower down an attendant, pick-off a stranded subject, then continue lowering to the ground).
   - Rigging overview including location of the edge transition, rope alignment, and focal points. A helpful technique to visually indicate these points is to take one of the mainlines, throw the end over the edge at the desired edge transition, then walk it back along the rope alignment and set the bag at the desired focal point location. This eliminates any confusion among the team as to where these critical points are located. Contrasting colored main lines are preferred to avoid confusion.
   - The team lead may point out desired anchor points if the team is less experienced. The team lead may also indicate focal point placement only and experienced riggers will determine appropriate anchors and focus them independently.
   - Any other site specific considerations?

10. EDGE MANAGEMENT

10.1 OVERVIEW

Edge management is performed by the edge attendants. This is one of the more time consuming and complex positions on the technical rescue team. Edge attendants should possess strong rope skills so they can move up and down the rope and perform work over the edge when necessary. One edge attendant position may be sufficient for the operation, but if there is a litter involved then two is ideal. Edge attendant duties include:

1. Pad the cliff edge with edge protection (Figure 10.1-1).
2. Rig the high directional if applicable.
3. Assist the litter attendant with the edge transition.
4. Relay communications between the litter attendant and team lead.
5. Monitor tension in the mainlines.
6. Serve as an extra pair of eyes and safety overwatch (the edge attendants are typically the only personnel that can see what's happening both in the vertical environment and with the rigging up top).

Figure 10.1-1 - Edge Attendant placing edge protection

10.2 EDGE ATTENDANT SAFETY LINE

Edge attendants work in the hazard zone at the edge of the cliff. For this reason they must be tied in to a safety line.

Typically edge attendants work at the top of the cliff where their feet are their primary attachment to the ground and the safety line is a backup. However, sometimes edge attendants work over the edge in vertical terrain. In this case, they need to be secured by a second safety line for redundancy.

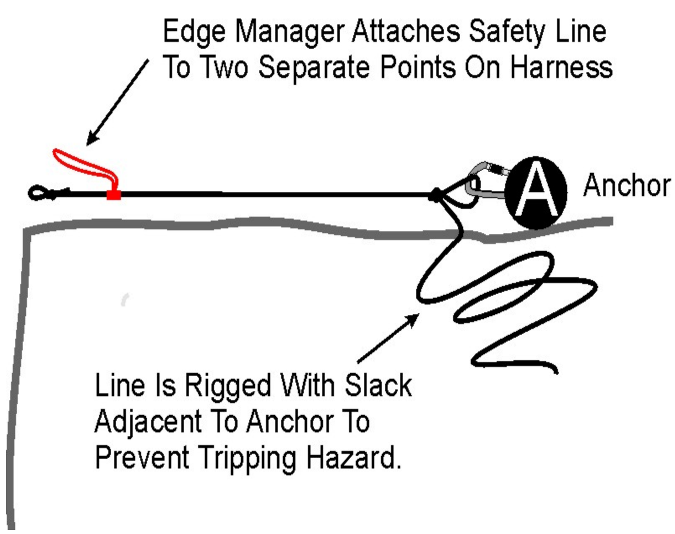


Figure 10.2-1 - Edge Safety Line

WARNING: A "tripping hazard" exists if the edge attendant's line has slack piled near the edge.

- The edge attendant's safety line should generally be clipped into a separate anchor from the main line anchor.
- The edge line should be rigged with just enough length for the attendant to work comfortably up to the edge, without going over. Excess rope is situated out of the way behind their anchor.
- The edge attendant should attach to their safety line in two ways: first "tie in hard" to the end of the rope such that they cannot go over the edge and second, use an adjustable attachment such as a GRIGRI or prusik to move up and down the rope.

10.3 EDGE PROTECTION

Sharp edges will cut rope at much lower forces than the rope's breaking strength. The edge attendant must ensure the rope is protected from sharp edges.

To place edge protection, rig an "edge pro line". This can be an 8 mm cordelette secured on a single anchor point up top then tossed over the edge. Attach edge pro to this line using a clove hitch or small prusik for adjustability. When the operation is complete, pull up the edge pro line to de-rig all the edge pro at once.

Often there are several edges the rope contacts before going vertical (Figure 10.3-1). Either the edge attendant or litter attendant should pad lower edges.

If considered appropriate for the site, edge attendants may use a rock hammer to dull a sharp edge prior to placing protection.

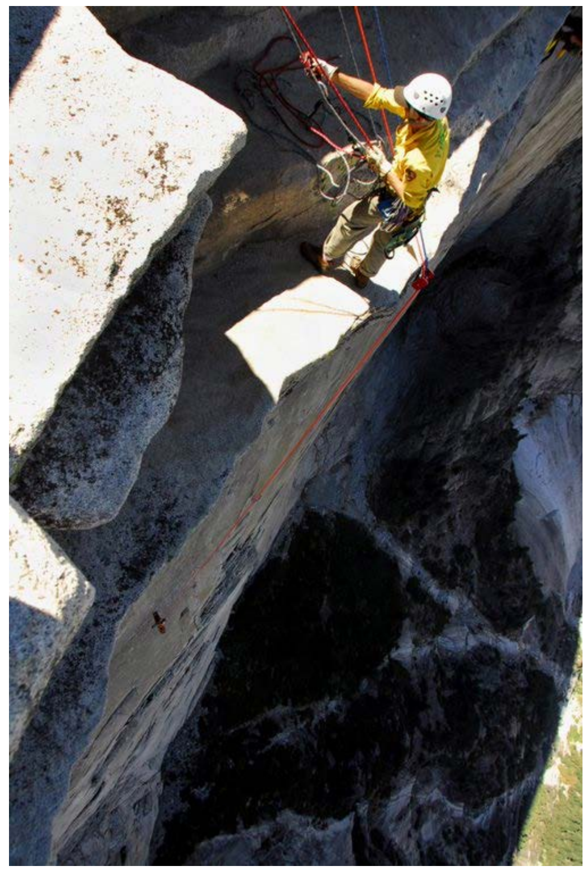


Figure 10.3-1 Edge attendant protects a secondary edge on Half Dome (NPS photo).

10.4 ARTIFICIAL HIGH DIRECTIONALS

Negotiating a sharp cliff edge with a loaded litter is dramatically easier when the main line is directed up through a high point near the edge. This facilitates a much smoother edge transition and eliminates the "edge trauma" a patient might otherwise experience.

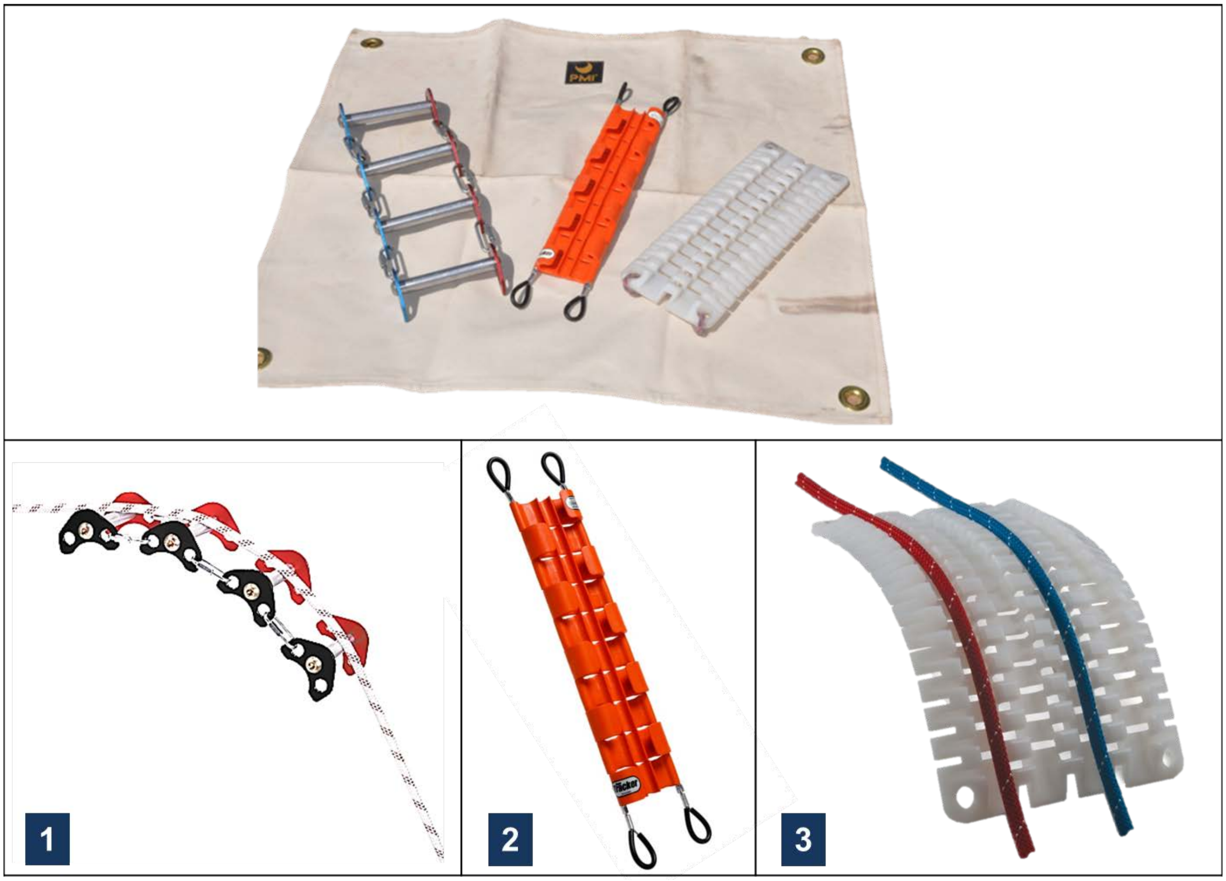


Figure 10.3-2 - Edge Protection. PMI Rope canvas tarp shown with several with edge protection devices. 1. Petzl Set Caterpillar (P68). 2. SMC Rope Tracker. 3. CMC Rescue Utra-Pro™ Edge Protector constructed of high density polyethylene (HDPE).

A natural rock stair-step or a well-located tree with the attachment of a directional pulley can provide rescuers with an easy solution. However, lacking such a natural rigging opportunity an artificial high directional (AHD) can be engineered with a tripod, A-frame or gin pole configuration, which are constructed respectively with either three legs, two legs or a single leg.

Figure 10.4-2 - Artificial High Directionals. © CMC Rescue and SMC.

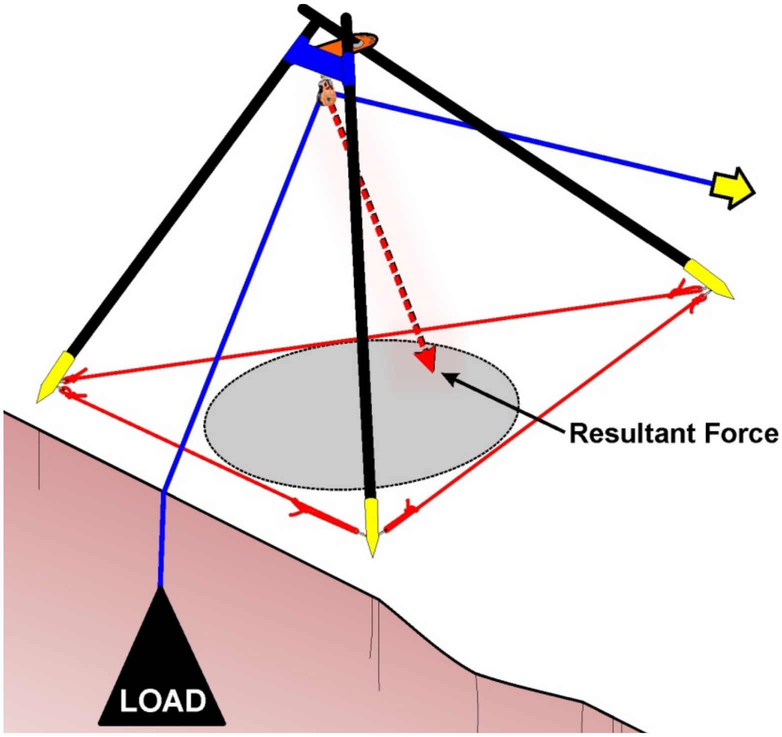


Figure 10.4-3 - Resultant force vector. Created by a rope running through a directional pulley on an artificial high directional (shown in tripod configuration).

There are several commercial AHD's available including the Arizona (AZ) Vortex and SMC TerrAdaptor™ (Figure 10.4-2). A major disadvantage of any AHD is the bulk and weight of the equipment that must be transported to a remote rescue scene.

A three-legged tripod configuration is the most stable arrangement, requiring less rigging effort. A-frame (bi-pod) or gin pole AHD's involve less material to transport to the scene, but the trade-off is increased time to properly secure these with additional guy lines. This chapter will only address rigging tripod configuration AHDs.

A high directional tripod has a high center of gravity. However, when a load is properly applied in a downward manner the compression forces stabilize it in place. When the rope, threaded through pulleys at the top of an AHD is tensioned with a load at one end and secured at the other end, there is a "resultant" force vector created by the interior angle of the rope at the pulley. This can be visualized by projecting an imaginary line from where the base of the pulley is pointing to the ground (Figure 10.4-3). A resultant vector located well inside the footprint of a tripod stabilizes it in place. However, when the resultant force vector is located outside of the tripod base, the device will topple in the direction of this force. The goal in rigging a tripod is to have the resultant force as close to the center of the three legs as possible.

Figure 10.4-4 - AZ Vortex Artificial High Directional in tripod configuration.

An artificial high directional, if not properly rigged, can topple over in a catastrophic manner. It is crucial to understand the forces generated in specific situations and configurations.

To install, assemble the tripod a short distance from the cliff edge and then move it into place with one person on each leg. The AHD must be tethered to an anchor to prevent it from toppling over the cliff during installation. This tether is left in place during the operation.

When the top of the AHD is subjected to downward compression the legs are forced apart. The legs therefore must be physically stabilized by either anchoring the feet to the surface or hobbling the legs with separate straps or cordage. The legs should be hobble strapped separately, one strap between two legs, since encircling all three legs with a single hobble strap still permits two legs to spread. Ensure the straps are snug and rigged low to the ground to prevent a tripping hazard (Figure 10.4-5).

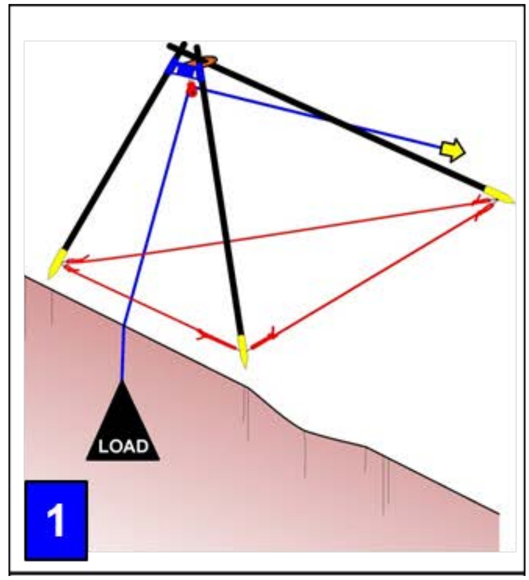


Figure 10.4-5 – Hobble strap legs separately.

11. MECHANICAL ADVANTAGE

11.1 PULLEY SYSTEMS

It is believed that in 1500 BC people in Mesopotamia used rope pulleys for hoisting water. Archimedes of Syracuse, Greek mathematician, invented the first compound pulley systems (287 BC - 212 BC). According to Greek historian Plutarch, Archimedes moved an entire warship, laden with men, using compound pulleys and his own strength.

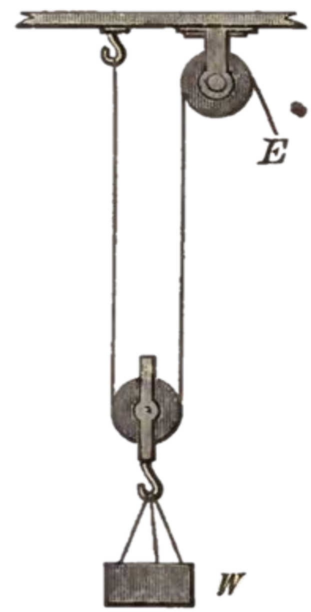


Figure 11.1-1 - Mechanical advantage pulley system with fixed and moveable pulley. From First Principles of Physics. H. Carhart and H. Chute. 1912.

Pulley systems are actually simple machines, which serve as "force multipliers". A **machine** is a device designed to change the direction or the magnitude of a force required to do useful work, or to transform and transfer energy. In rescue applications, pulley systems permit a rescuer to raise a load by applying a force that is less than the load itself.

The **mechanical advantage** of a pulley system is calculated as the ratio of the load in comparison to the amount of force required to move the load. If a pulley system employs a 1 kN force to move a 2 kN mass, then the mechanical advantage is calculated as 2:1. Mechanical advantage is gained at the expense of endurance. Even though less force is required, it must be employed over a greater distance.

Rescue pulleys are comprised of a wheel the rope rolls over, which is known as a **sheave**. The sheave is supported by an **axle** and held in place by the **side plates**.

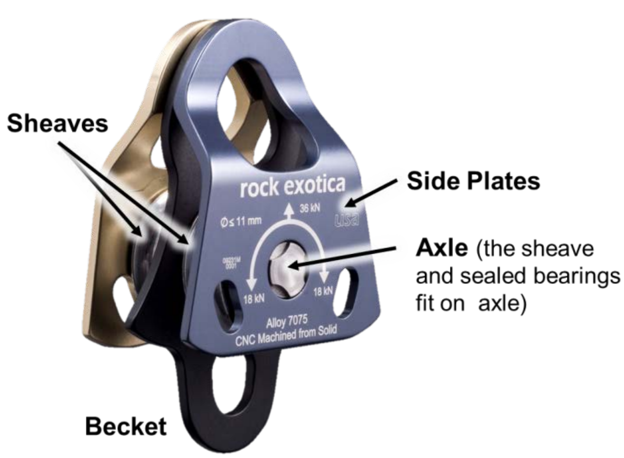


Figure 11.1-2 - Double sheave pulley. Rock Exotica double sheave pulley. Original image © Rock Exotica.

Pulley efficiency is reduced as a result of friction loss and other factors, such as bending and unbending of the rope. The measure of pulley efficiency is calculated by the output force coming out of a pulley over the input force going into a pulley, which is expressed as a percent. As an example, if a 95N force is required on one side of a pulley to hold a 100N load, then the efficiency of the pulley is calculated to be 95% (95/100). 90-95% is the typical efficiency of a rescue pulley (Figure 11.1-3).

Factors influencing the efficiency of a pulley, as well as the entire pulley system, include:

- Pulley **sheave** size. A larger diameter sheave gives a larger moment to overcome bearing friction. Also, the radius of rope bending and unbending is less, therefore more energy is transferred through. The sheave is the wheel which the rope runs on.
- Pulleys with self-lubricating bushings are efficient. However, sealed ball bearings are more efficient and require very little maintenance.
- The angle of the load line and haul line, since lines kept at 180° result in improved pulley system efficiency.
- Threading pulleys to ensure ropes don't rub on each other, or result in twisting, which decreases efficiency. Twisting can be lessened with the use of pulleys with swivel connections.

Figure 11.1-3 - A pulley with 95% efficiency is depicted in this example. Original image © Rock Exotica.

Efficiency of a pulley system is also evaluated in terms of what will provide the best output for the operation. If a 5:1 pulley system will comfortably move a load, then using a 12:1 pulley system would be less efficient, since it requires more time and the movement of more rope through a system to move the load the same distance.

The following terminology is used to describe the mechanical advantage of a pulley system:

Ideal Mechanical Advantage (IMA) — estimated mechanical advantage without taking into consideration any friction loss in the system. When we refer to a pulley system as 3:1, 5:1, 9:1 and so forth, we are referring to the IMA.

Theoretical Mechanical Advantage (TMA) — refers to the mechanical advantage that has some calculation of efficiency losses, but it is not measured.

Actual Mechanical Advantage (AMA) — measured mechanical advantage that will be actually experienced or observed when friction loss is taken into account.

Within a pulley system, **traveling pulleys** move toward the anchor or load when the system is being pulled on to move a load. The pulleys which remain fixed and do not move when a pulley system is being pulled upon are known as **stationary (fixed) pulleys**. As a pulley system is employed to move a load it will collapse to the point where one or more traveling pulleys will make contact with a stationary pulley. This results in not being able to move the load any further. The pulley system is then re-expanded, through a **reset**, to the original size or **throw distance**, so that hauling may continue.

Haul Prusik — the Prusik closest to the load which serves to attach the pulley system to the main line.

Ratchet Prusik — (also referred to as the progress capture) the ratchet prusik within a pulley system works in conjunction with a pulley to advance it up a line during movement of a load. A ratchet prusik holds tension on the line during a reset, preventing it from going backward, so that progress is not lost. A ratchet prusik used in conjunction with a prusik minding pulley creates a **self-minding ratchet**, which will tend itself during operation of the pulley system (Figure 11.1-4).

Figure 11.1-4 - Ratchet Prusik

Pulley systems can be rigged by either using the main line itself or using a separate line "ganged" (also referred to as piggy-backed) onto the main line (Figure 11.1-5). In order to have a working knowledge of pulley systems, it is important to understand some basic principles that distinguish one system from another.

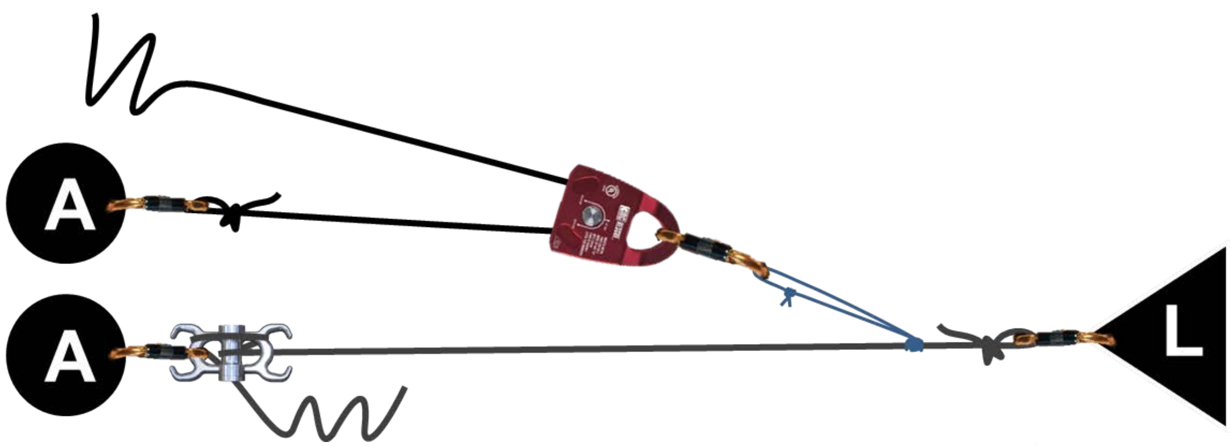


Figure 11.1-5 - Simple 2:1 ganged onto the mainline

Pulley Strength— in a single pulley half the load is on one side of the rope and half is on the other. The total load on the pulley is thus 2X the mass that is being moved. The force on a double pulley is still twice the load since each individual rope is supporting 1/4 of the load). This strength rating is illustrated on the side of a pulley (Figure 11.1-6).

Figure 11.1-6 - Pulley strength. This CMC Rescue Pulley (model 300301) has a rated breaking strength of 47 kN, which means a limit of 23.5 kN load to one strand of rope entering the pulley. Image © CMC Rescue.

Pulley system classifications include:

- Simple systems
- Compound systems
- Complex systems

11.2 SIMPLE PULLEY SYSTEMS

These are identified by having one continuous rope flowing back and forth between the pulleys toward the load and toward the anchor. Additionally, all pulleys traveling move toward the anchor and at the same speed. All pulleys at the anchor remain stationary and tension in the rope is constant throughout the pulley system (Figure 11.2-1).

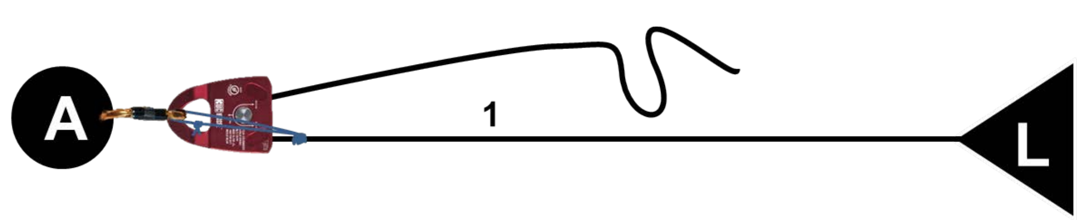
In a simple pulley system, when the rope end terminates and is attached at the anchor, then the IMA will result in an even number (e.g., 2:1, 4:1, 6:1, etc.). When the rope end terminates and is attached at the load, then the resulting IMA will be an odd number (e.g., 3:1, 5:1, etc.).

If the last pulley in simple pulley system (closest to the haulers) is attached to the anchor, it does not add mechanical advantage, but serves as a change of direction.

The IMA can be calculated for a simple pulley system by counting the number of rope strands directly supporting the load (located on the load side of the pulley system).

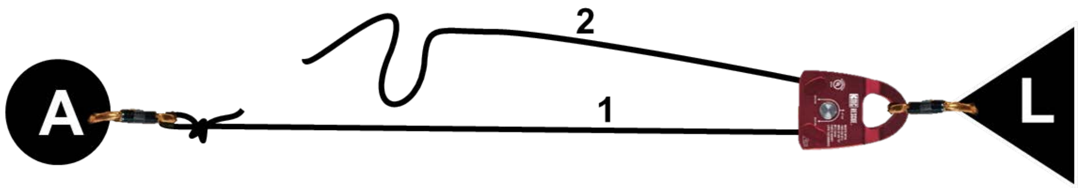
The number of pulleys required to construct a simple pulley system, without a change of direction, is one less than the IMA. In order to incorporate a self-minding ratchet at the anchor as a progress capture device, the IMA of a simple pulley system must be an odd number. A self-minding ratchet can be constructed with a prusik hitch and prusik minding pulley (Figure 11.2-1a) or a self-ratcheting device, such as an MPD™ (Figure 11.2-2)

Figure 11.2-1 (A through J) Simple Pulley System Examples

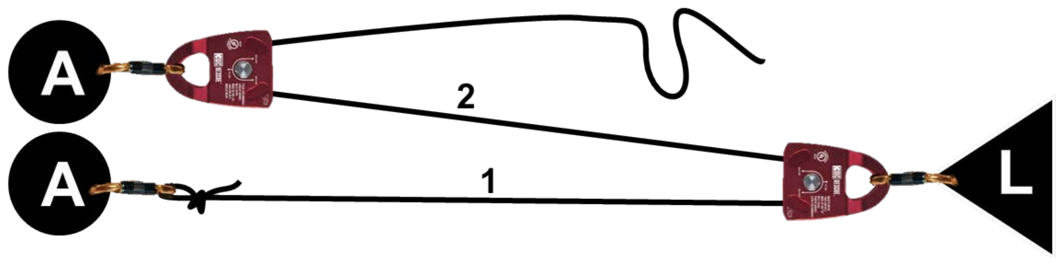


(a) Simple 1:1 with change of direction

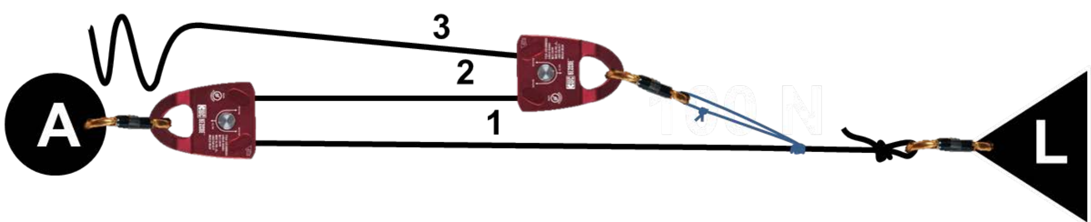
Figure 11.2-1 (A through J) Simple Pulley System Examples



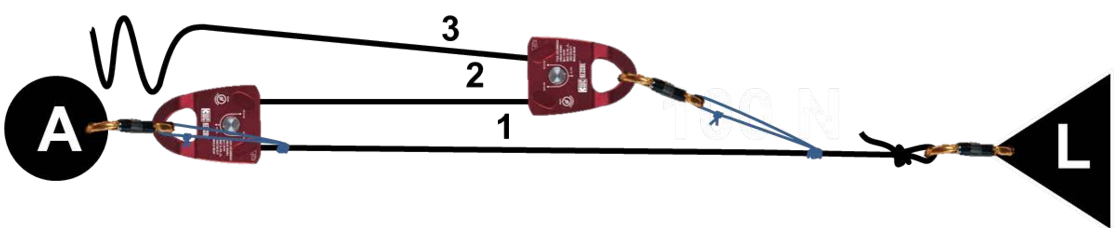
(b) Simple 2:1



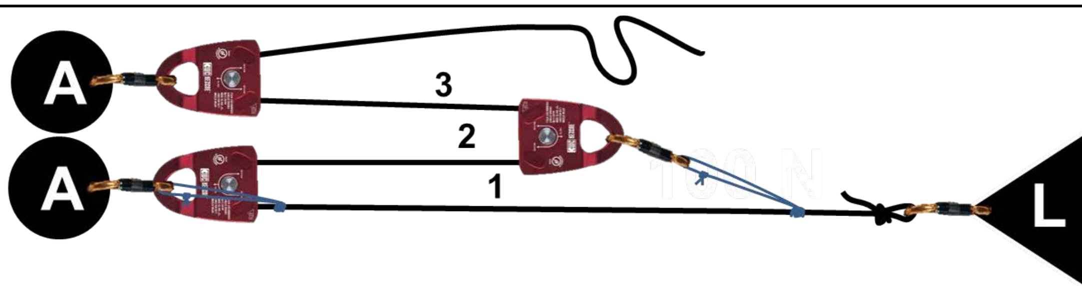
(c) Simple 2:1 with change of direction



(d) Simple 3:1

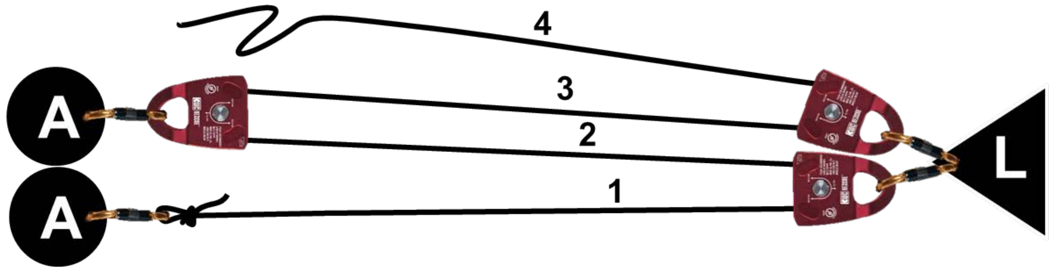


(e) Simple 3:1 with ratchet Prusik

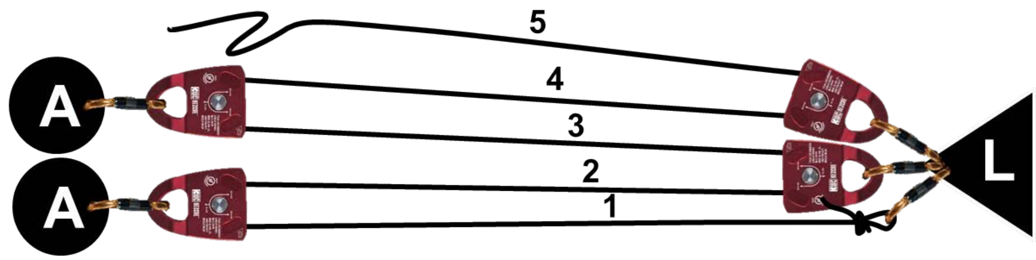


(f) Simple 3:1 with change of direction

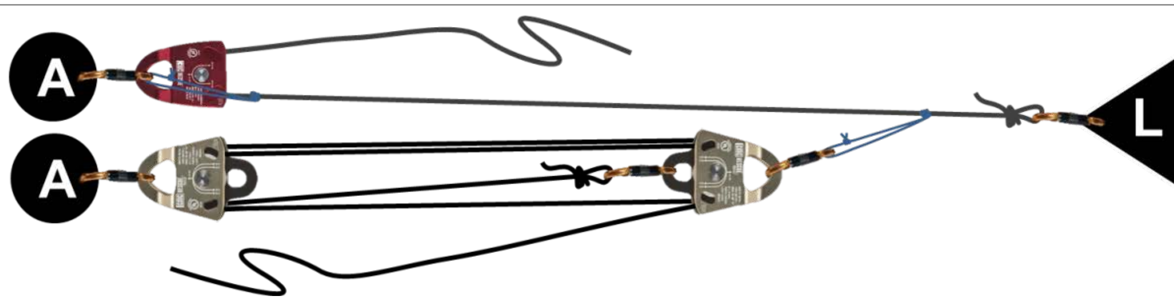
Figure 11.2-1 (A through J) Simple Pulley System Examples



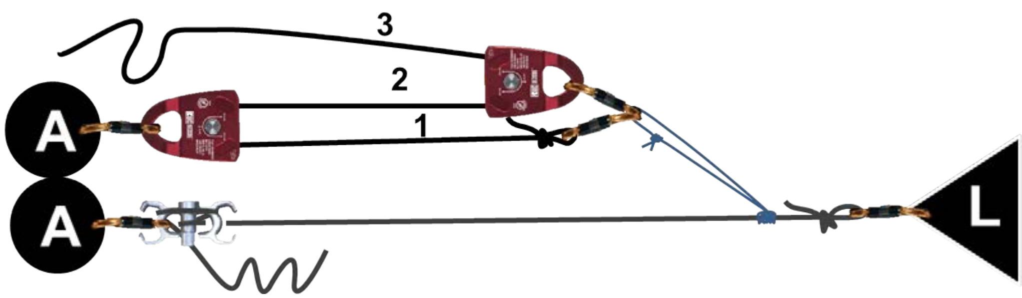
(g) Simple 4:1



(h) Simple 5:1

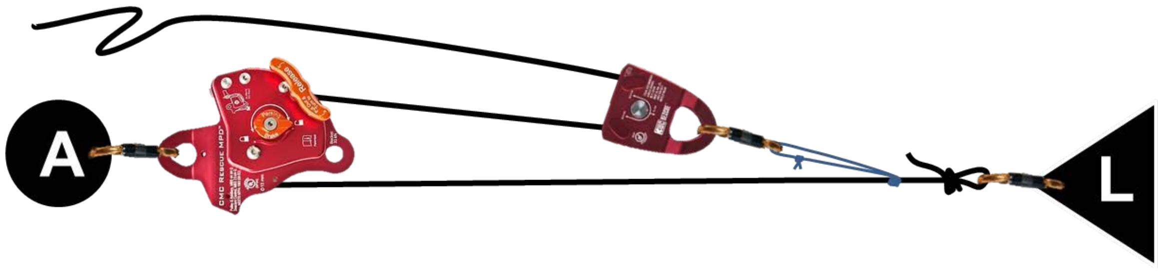


(i) Simple 5:1 (constructed with double pulleys) ganged on to mainline

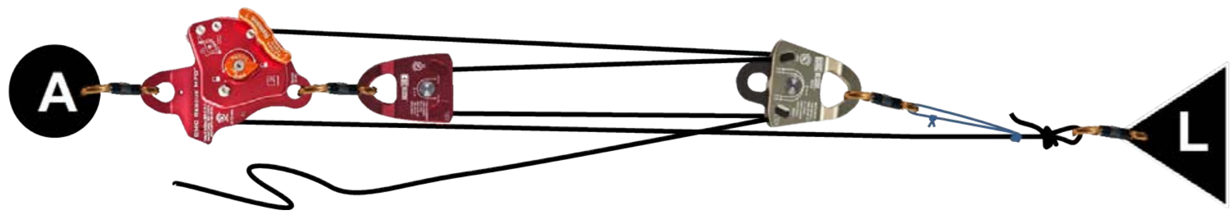


(j) Simple 3:1 acting on the mainline

Figure 11.2-2 - Simple pulley systems utilizing the MPD™ (Multi-Purpose Device) as a ratchet



(a) Simple 3:1 using MPD™



(b) Simple 5:1 using MPD™

11.3 COMPOUND PULLEY SYSTEMS

Compound pulley systems are identified as one simple pulley system acting on another simple pulley system (Figure 11.3-1). Traveling pulleys in the system move towards the anchor at different speeds. Compound pulleys systems are useful because they can provide greater mechanical advantage than simple systems for the same number of pulleys.

The IMA of a compound pulley system is calculated by multiplying the individual IMA of each simple pulley system together. A simple 2:1 pulling on a simple 3:1 results in a compound pulley system with 6:1 IMA.

If using a compound system that is comprised of two dissimilar MA simple pulley systems, the system with the smaller MA will collapse first. To maximize efficiency in raising a load with the fewest resets, locate the pulley systems so the system with the higher MA is pulling on the lower MA system (e.g., have a 3:1 pull on a 2:1 in a compound 6:1).

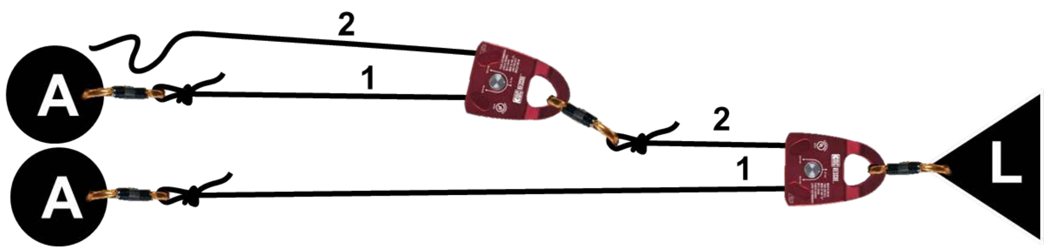
Positioning sufficient distance between the anchor points of the individual simple pulley systems in a compound system can improve the throw distance per reset by allowing both systems to collapse at the same time. If a compound pulley system is comprised of two simple 3:1 systems, then the rearward (furthest from load) system must have a reset distance of three times that of the forward system. This is because the three times more rope must be pulled through the rearward 3:1 than the forward 3:1.

To achieve the highest MA with the least number of pulleys requires constructing a compounded system of a 2:1 simple pulley system acting on a 2:1 simple pulley system, acting on a 2:1 and so forth.

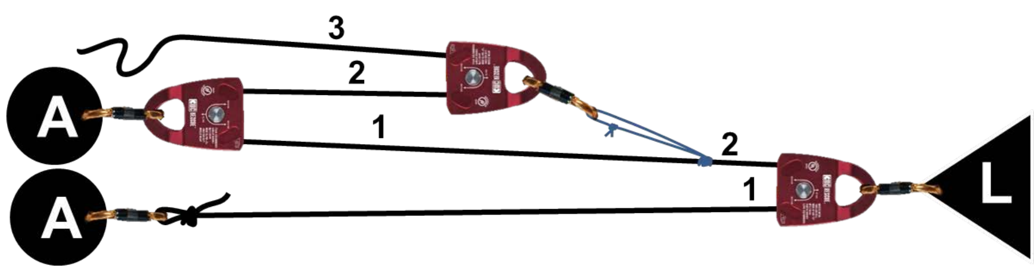
As each pulley is added to such a system, the mechanical advantage increases exponentially (e.g., 2:1, 4:1, 8:1, 16:1, 32:1, etc.).

When constructing a compound pulley system, critically think of all the possible combinations that when multiplied together will equal your desired MA; then consider the advantages and disadvantages of each and determine which combination will best meet your needs given your available equipment and working constraints.

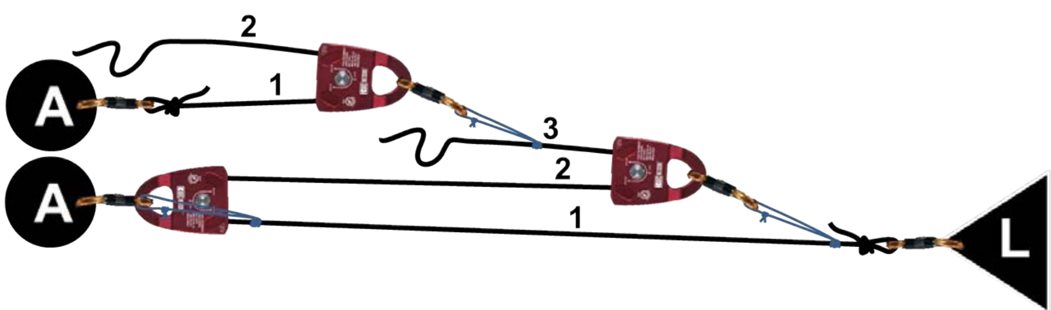
Figure 11.3.1 - Compound Pulley Systems Examples



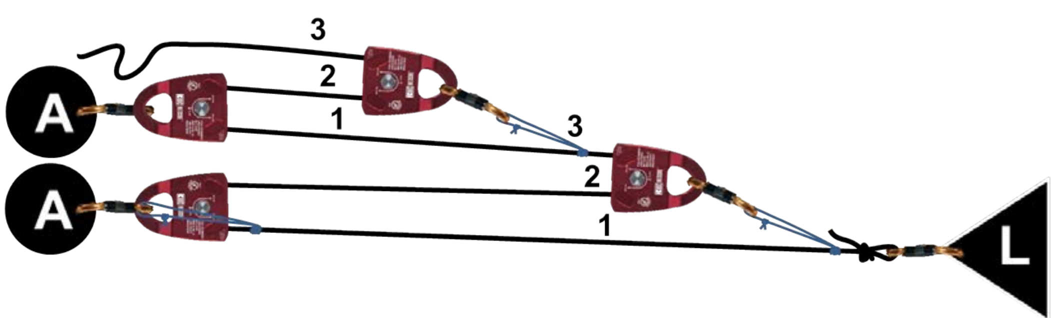
(a) Compound 4:1 (Simple 2:1 pulling on Simple 2:1)



(b) Compound 6:1 (Simple 3:1 pulling on Simple 2:1)



(c) Compound 6:1 with a ratchet (Simple 2:1 pulling on a Simple 3:1)



(d) Compound 9:1 (Simple 3:1 pulling on a Simple 3:1)

11.4 COMPLEX PULLEY SYSTEMS

Complex pulley systems do not meet the definition of either a simple or compound system; rather they involve more variables in rigging (Figure 11.4-1). Complex pulley systems can have pulleys moving toward the load and the anchor at the same time. With some rare exceptions, complex pulley systems are employed less frequently within rescue. Fortunately the same objective can be achieved with simple or compound systems which are easier for rescuers to understand and rig.

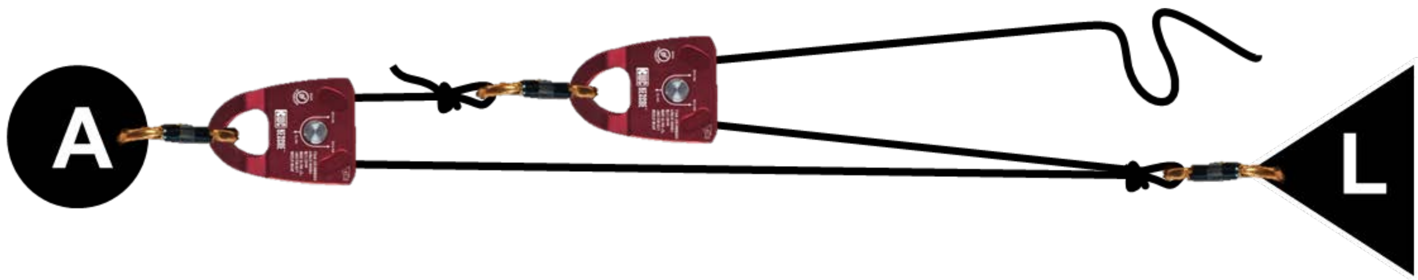


Figure 11.4-1 - Complex 3:1 (Spanish Burton)

11.5 DESCRIBING PULLEY SYSTEMS

Through common terminology rescuers can accurately describe a specific pulley to be employed in a rescue. Stating "build a 3:1 simple system" is more precise than saying "z-rig" (common slang for this pulley system). A request for a "compound 6:1 with a simple 2:1 acting upon a simple 3:1" provides clear direction to personnel assigned to rigging on an incident.

A pulley creating a change of direction provides no mechanical advantage and is used to redirect the direction of pull on a rope (Figure 11.5-1). This is employed in situations where it may be advantageous to have rescuers pull downhill or through a natural clearing.

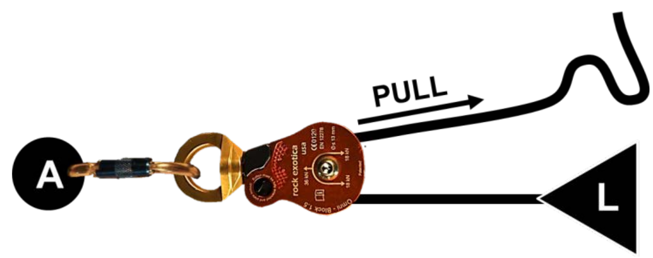


Figure 11.5-1 - Simple 1:1 with a change of direction.

11.6 CALCULATING MECHANICAL ADVANTAGE

Mechanical advantage in a pulley system is achieved by increasing the number of times an initial input force is applied upon the load. This is achieved in numerous rigging possibilities with simple, compound or complex pulley systems. The input force is the tension applied by pulling on the system and it is expressed as one unit of tension. Understanding how this one unit is transferred through a pulley system permits calculating the IMA, which is referred to as the "T-Method" (Tension Method).

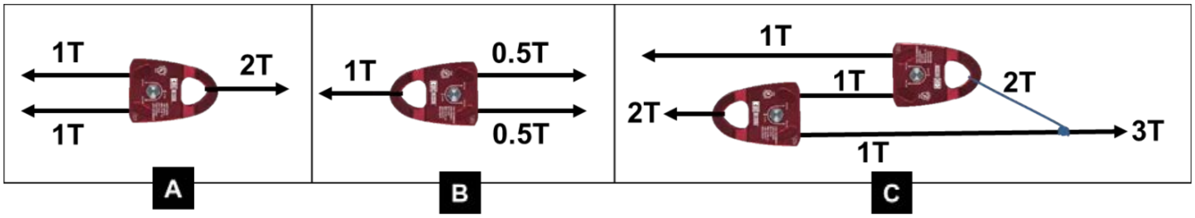


Figure 11.6-1 - T Method Examples

By assigning one unit of tension (T) to where the pull is applied to the system, then following the path of the rope through the pulley system to the load itself, the IMA can be determined by keeping track of how that initial unit of tension is distributed throughout the system. Simply compare the amount of tension that is applied to the load with the input unit of tension.

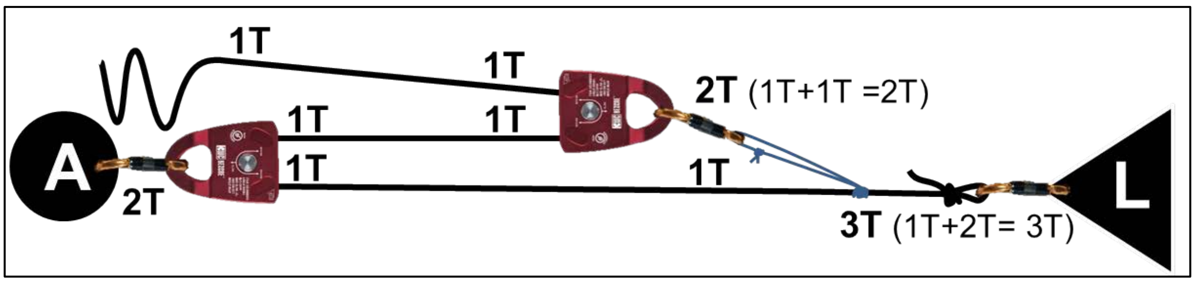


Figure 11.6-2 - Simple 3:1 Pulley System illustrating T-method

Understand that wherever a junction occurs with the ropes of the pulley system, such as one rope acting on another or one rope acts upon more than one rope, then the tension on one side of the junction must be equal to the tension on the other side of the junction. Additionally, on each side of the junction, the tension must be distributed appropriately (not always equally) to each rope. As an example, if a rope having one unit of tension makes a 180° change of direction through a pulley (considered a junction), then whatever that pulley is connected to receives two units of tension (Figure 11.6-1). In other words, two ropes each having a tension of one (two total units of tension) are acting on and opposed by what the pulley is connected to. Some examples of this principle being applied are illustrated in Figures 11.6-3.

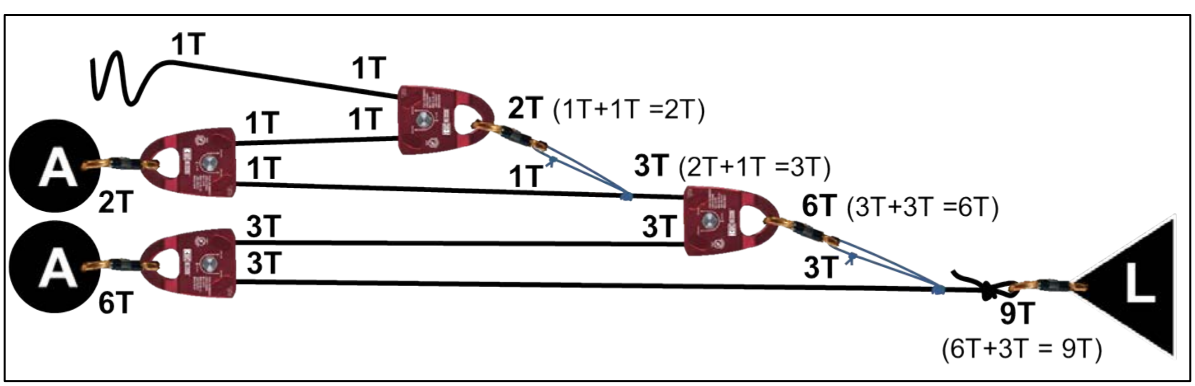


Figure 11.6-3 - Compound 9:1 Pulley System illustrating T-method

11.7 CALCULATING ACTUAL MECHANICAL ADVANTAGE

Again, the actual mechanical advantage (AMA) is the mechanical advantage that will be actually experienced or observed when friction loss is taken into account. The greatest friction loss occurs when ropes come into contact with pulleys. If a carabiner is used in place of a pulley, then even greater friction loss occurs.

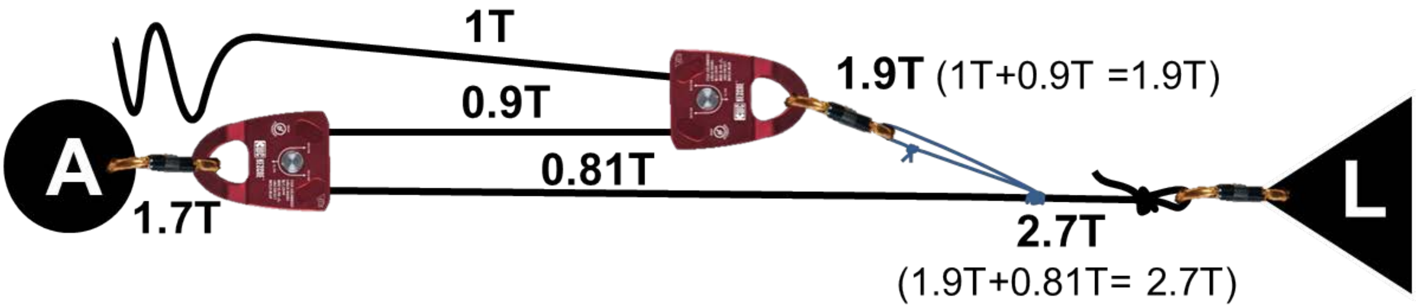


Figure 11.7-1 - Simple 3:1 or 2.7 AMA

To calculate the losses due to friction, one must know the efficiency of the pulleys being used. Using the pulley efficiency information, friction loss through the system can be calculated. Figure 11.7-1 shows the calculations for a pulley system with pulleys that have an efficiency of 0.90.

Assuming that the rescuers pull on the pulley system with one unit of tension, only 0.90T will be transferred past the first pulley. When that 0.9T reaches the second pulley, only 0.81T will be transferred onward (0.9 X 0.9 =0.81) as the friction loss is compounded over two pulleys. Follow this process all the way through the pulley system. When you are finished, use the T-Method to determine the final AMA, which in this situation is 2.71:1.

If higher efficiency pulleys are used (e.g., 95%), the AMA is increased to 2.85:1, which is closer to the IMA of 3:1. Also important to note, is that if you are using pulleys of different efficiencies, less loss occurs if the most efficient pulley is placed closest to the pullers. This is because the loss at the first pulley is compounded throughout the entire system.

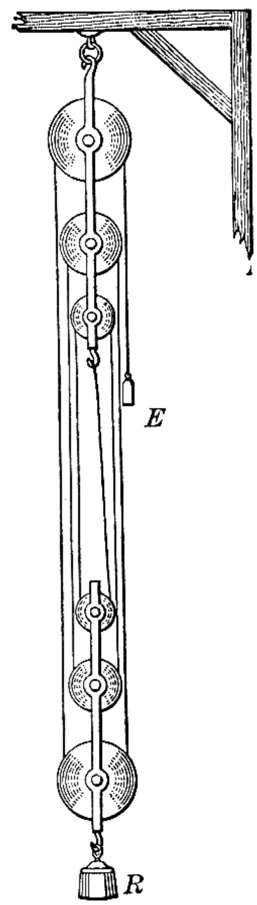


Figure 11.7-2 Mechanical advantage pulley system with fixed and moveable pulleys. From First Principles of Physics. H. Carhart and H. Chute. 1912.

11.8 PULLEY SYSTEM RIGGING

Prusiks are utilized as haul and ratchet rope connections since they can handle shock forces without catastrophically failing a line. Prusik hitches employed in such a manner need to be triple wrapped (six coil) to prevent slippage under load. A 6:1 Schwabish hitch may also be used in this application and is becoming more common.

Do not use a mechanical ascender in a pulley system in place of a haul or ratchet Prusik.

Figure 11.8-1 - YOSAR haul team conducting a raise on El Capitan.

- Obtain the greatest mechanical advantage in a hauling system by reducing as much friction as possible through rigging lines so they do not directly touch sharp rock edges or run directly along the ground.
- A change of direction pulley, which adds no mechanical advantage to a hauling system, is frequently employed to orient the line in a position of convenience for hauling (e.g., pulling at a right angle from the main anchor).
- Keep mechanical advantage lines parallel for maximum practical mechanical advantage. A directional pulley may be used to achieve this if hauling is being directed away from the main pulley system.

As a general guideline, the average person can provide **209 Newtons (46 lbs)** of gripping ability (combination of grip strength and coefficient of friction of the item being gripped) on a rope. This is useful to know in planning a raising system and determining how many haulers will be needed. By simply rounding off to 50 lbs of force (222 Newtons) per hauler and multiplying by the mechanical advantage of the pulley system, the theoretical output (not accounting for friction loss) of the pulley system can be determined.

A common error is pulling too hard and too fast, which is very dangerous since the load can be jammed in a crevice or injure rescuers on the line. The goal is to generate a smooth raising effort on the line. **Avoid a "heave-ho" pull on the haul system.** This can cause the litter to bounce and create excess abrasion on the main line. If a heave-ho is occurring, increase the mechanical advantage or increase the number of haulers.

Figure 11.8-2 - Haul Team Merry-Go-Round. Haul team members pull in both directions as they move in a circular pattern.

An efficient technique for a haul team is to employ a "merry-go-round" method (Figure 11.8-2), which permits personnel to pull on the haul system as they move in both directions. This requires establishing a change of direction back toward the anchor. The haul team is situated within the bight formed by the change of direction. The haulers walk in a circular progression pulling on the primary strand coming from the load and then reversing direction pulling on the same strand where it comes out of the change of direction pulley. This maximizes the number of hands pulling on the rope and permits movement as the pulley system collapses. Again, this technique does place personnel "standing inside a bight," which is typically avoided. In this situation the change of direction pulley, creating the bight, is under significantly less tension than the pulley located at the haul Prusik, which is connected directly to the load and would be a more likely failure point.

11.9 MECHANICAL WINCH SYSTEMS

Marine sailing winches have been repurposed as appliances for rope rescue applications by manufacturers including SkyHook™ Rescue Systems and Kong (Italy). Sailing winches rely on leverage to generate torque. The external lever is the winch handle and the internal lever is the revolving sets of rotary levers called gear sets. Two-speed self-tailing capstan winches provide tremendous mechanical advantage in a confined area. Changing the rotation of the handle from clockwise to counterclockwise changes the speed and power ratio (mechanical advantage) of a two-speed winch.

Figure 11.9-1 - Harken LokHead Winch. Photo by Ken Philips.

Another innovative design is the hand-powered Paillardet Winch, developed in collaboration with the P.G.H.M. (High Mountain Constabulary) in Chamonix, France. The unit weighs 10 kg (22 lbs), handles a 300 kg (660 lb) working load and raises at a speed of 17 m (56 ft) per minute. It can be fitted with a hydraulic power unit and is capable of handling rope, metallic cable and aramid cable.

Additional powered rope winches and ascenders are manufactured by Act Safe Systems AB (Sweden), PowerQuick Concepts Inc. and Harken Industrial, which are frequently employed by industrial rope access technicians. The Harken PowerSeat™, powered by a gas 4-stroke engine, can be employed in a compact mode and attached to fixed-point rigging for rescue applications. The unit weighs 14.5 kg (32 lbs) and has a rated safe working load of 273 kg (600 lbs). The Harken PowerSeat™ has an ascent speed of 11 m (39 ft)/min under max load.

There are numerous winches on the market that have been developed or repurposed for rescue work. One example is the Harken LokHead (Figure 11.9-1) but many others are commercially available. Be sure to read and follow manufacturer's instructions and receive appropriate training before use. Care must be taken when operating mechanical winches as the tactile feel of the load is lost. Injury could occur to the patient and attendant if they are dragged through, or jammed into terrain features.

11.10 EMPLOYING A LOAD CELL IN RIGGING SYSTEMS

Measuring a mass involves placing a weight on a scale. However, measuring force, speed or torque is significantly different. Mechanical dynamometers, employing an internal spring scale, originally developed to measure tension in telephone wires[28], were previously used to measure forces in rope rescue systems. These have been replaced by modern digital load cells which convert a force to an electronic signal through the use of a transducer. This conversion is accomplished through the force being measured deforming a strain gauge. The strain gauge measures the deformation (strain) as an electrical signal, due to changes in the effective electrical resistance of the wire. This permits real-time feedback of the actual force being generated in a rigged rope system. Employing a load cell during training provides a valuable tool to examine and validate the actual forces being applied in hauling systems or other applications, such as suspended highlines. When employing a load cell within a system, it should always be backed up for safety in the event of catastrophic failure.

Rock Exotica produces a compact aluminum load cell known as the Enforcer, which was co-developed by Kirk Mauthner and Helgi Hall. The Enforcer (Figure 11.10-1) is capable of maximum readings up to 20 kN (4, 496 lbf) and has a MBS of 40 kN (8,992 lbf). The small design facilitates "in-line" use in rigging systems. It is capable of two sampling modes, which include either a "slow" for monitoring rigged systems during use or "fast" for drop testing analysis (averaged 500 sampling points per second from 4,000 s/sec). The device has Bluetooth connectivity for data transfer and can obtain high resolution analysis of a dynamic event lasting up to four-seconds. Readings can be displayed in kg, kN or lbf. Swivel attachment points permit proper alignment of the load cell during usage. Calibration can be accomplished using a known load mass. Weight 14 ounces with batteries.

Figure 11.10-1 - Rock Exotica Enforcer Load Cell

[28] Dillon/Quality Plus, Inc. http://dqplus.com/pdf/mechdyna_L.pdf

12. LOWERING AND RAISING

12.1 OVERVIEW

This chapter covers lowering and raising systems. There are numerous variations of techniques and equipment used by teams across the NPS. This chapter presents one way to rig these systems. Before getting into rigging specifics, in general, rescue systems should be rigged to achieve the following attributes:[29] [30]

- Strength – Build rescue systems to a minimum of 20 kN breaking strength.
- Redundancy – No single piece of equipment is a critical point.

[29] Gibbs, Koprek. Two Tension or not To Tension. 2019.

[30] Mauthner, Kirk. EMBC Rope Rescue NIF Equipment Testing 2016.

- Force Limiting Capacity – The system will limit peak forces below material breaking strengths while also providing enough friction to maintain control of the load and prevent inertial runaway (Force limiting at 6-12 kN).
- Belay Competency – The system has a self-actuating hands-free auto-stop. If one part of the system fails, or the operators make a mistake, the system acts as a belay and stops the load from falling.

In addition to these attributes, there are several other important rigging considerations for raising and lowering operations:

- Edge Transitions – Edge transitions should be executed in a way that limits potential peak forces, i.e., when there is an abrupt edge the edge transition should be executed with the litter in vertical orientation against the rock, or a high directional should be utilized. If a high directional is used, rig both ropes through the high directional.
- Fall Factor – Minimize the fall factor by increasing rope in service when lowering over abrupt edge transitions. This does not require an excessive amount of rope in service, but ≥5 m is beneficial and permits throw distance for a raise.
- Rope Alignment – Ensure the edge transition, rope alignment, and focal points are all in alignment to prevent a pendulum swing.
- Sharp Edges – Pad sharp edges at all times.
- Stopping Distance – Systems should be rigged to minimize stopping distance.

12.2 PURPOSE BUILT VS. COMPONENT BASED SYSTEMS

There is a wide variety of rescue equipment on the market. Safe rescue systems can be built in numerous ways and with numerous combinations of equipment. Generally, equipment and systems can be divided into two camps: purpose built devices and component based systems.

Purpose built devices such as the CMC MPD™, CMC Clutch™, and Petzl Maestro™ aim to be "all-in-one" pieces of equipment that function as descent control, rescue belay, pulley, and progress capture. These systems require less individual pieces of equipment to rig. They make changeovers faster and they are useful as force limiting devices in advanced rigging systems like highlines and guiding lines. The downsides of purpose built devices are weight, singular use purpose, and the necessity for the operator to override the auto-stop function when used as a descent control device.
Component based systems are made up of individual pieces of equipment, each with a specific purpose. For example: a Black Diamond ATC™ for descent control, Bluewater VT™ prusik for auto-stop, and a pulley. The strengths of component based systems are that they are light weight, multipurpose, and adaptable for improvised rescue with equipment commonly carried by climbers and canyoneers. Both purpose built and component based systems are valuable tools, and rescuers should be familiar with the proper use, strengths, and weaknesses, of each.

12.3 TWO TENSIONED ROPE SYSTEM (TTRS) VS. DEDICATED MAIN, DEDICATED BELAY (DMDB) SYSTEM

There is an ongoing debate between TTRS vs. DMDB systems. This debate currently centers on abrupt edge transitions and whether TTRS or DMDB is superior in this application. After completing an abrupt edge transition, both camps are in agreement that having two tensioned lines is superior for the balance of the operation in order to minimize stopping distance.

In the case of an abrupt edge transition, supporters of DMDB systems prefer a tensioned main and un-tensioned belay. They argue that DMDB offers superior control of the load on one tensioned line vs two. They also argue that keeping the belay un-tensioned optimizes its ability to function as a hands free auto-stop. Once through the abrupt edge transition, DMDB system operators transition to a TTRS for the rest of the operation. In addition, if there is no abrupt edge transition (sloped edge or no edge), DMDB advocates tension both ropes from the outset of the operation.

Conversely, supporters of TTRS prefer two tensioned mainlines for abrupt edge transitions. They argue that two tensioned ropes provide for a more stable and smooth edge transition due to the lateral stability offered by two ropes and the dampening effect of two ropes sharing tension. They also argue that the simultaneous redundancy of two ropes sharing the load is superior to one rope taking all the load in the case of DMDB. There is also evidence that two tensioned ropes survive pendulum swings across sharp edges better than DMDB systems.

In the end, both systems have been tested and utilized in training and real world applications. Both are safe when executed properly. To keep this manual concise, only TTRS systems will be shown in this chapter. However, DMDB techniques are also valid, used by numerous NPS teams, and possess the advantages stated above.

12.4 COMPONENT BASED SYSTEMS

This section will show how to perform lowers, changeovers, raises, and knot passes using component based equipment. The pictures below depict an ATC as the descent control device. However, other devices may be used such as the Conterra Scarab® and CMC 3D™.

Component Based Lower

Figure 12.4-1 depicts a TTRS rope lower rigged with ATC and VT prusik. Note that the prusik is extended with a doubled up sling. This keeps it clear of the rigging. Also, note that the running

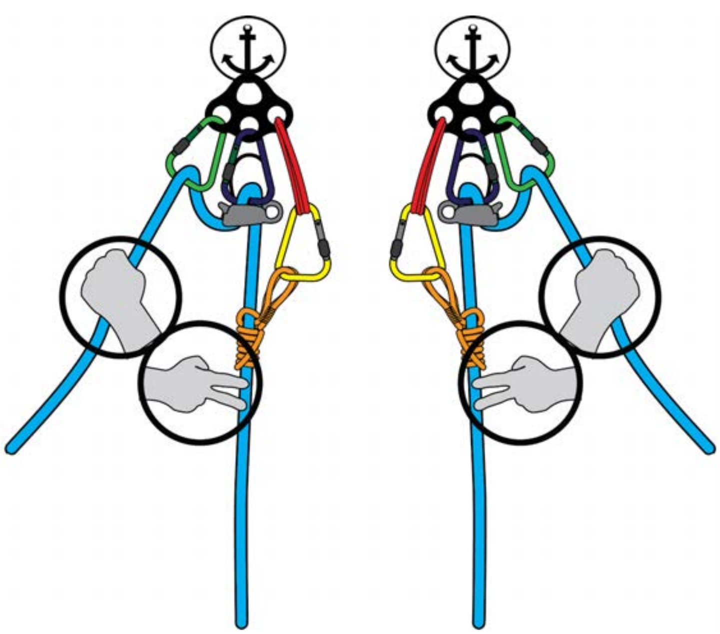


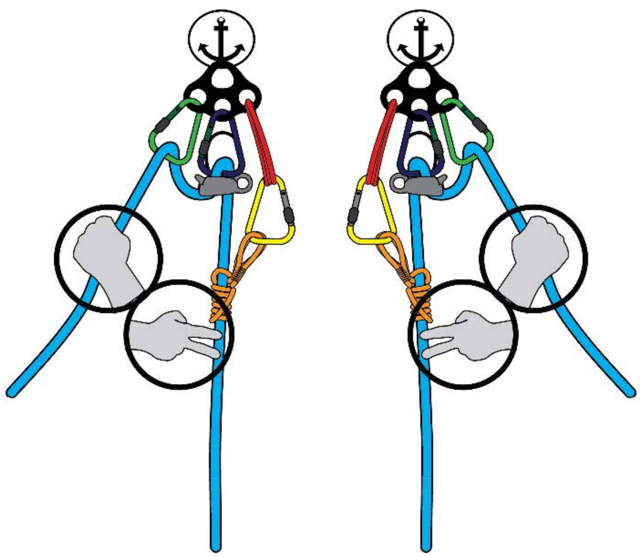
Figure 12.4-1 Two tensioned rope lower system using ATC and VT prusik.

end is re-directed through a carabiner on the rigging plate. This adds friction, especially important for two-person lowers, and can be more anatomical to operate. See Figure 6.3-10 on how to tie the VT prusik into a Schwabisch hitch.

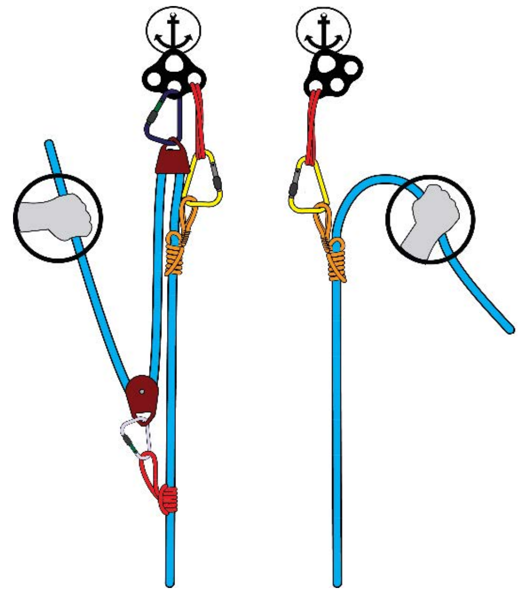
Component Based Changeovers

This section will cover changeovers: lower to raise and raise to lower while the system is weighted (aka "hot changeover").

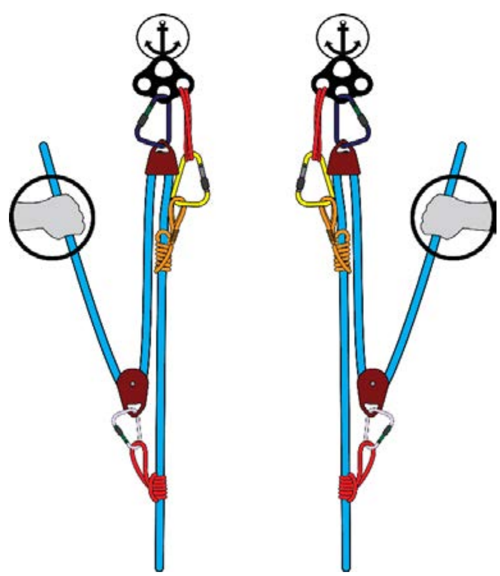
Lower to Raise Changeover (12.4-2A-C)



A. Set the load on the prusiks. Never disconnect or open the prusiks or their carabiners.

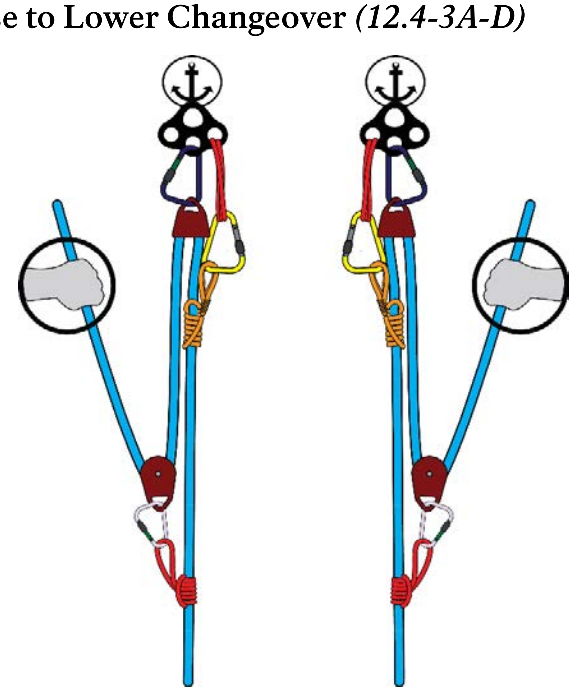


B. Disconnect the descent control devices (ATC's) and replace with a pulley system.

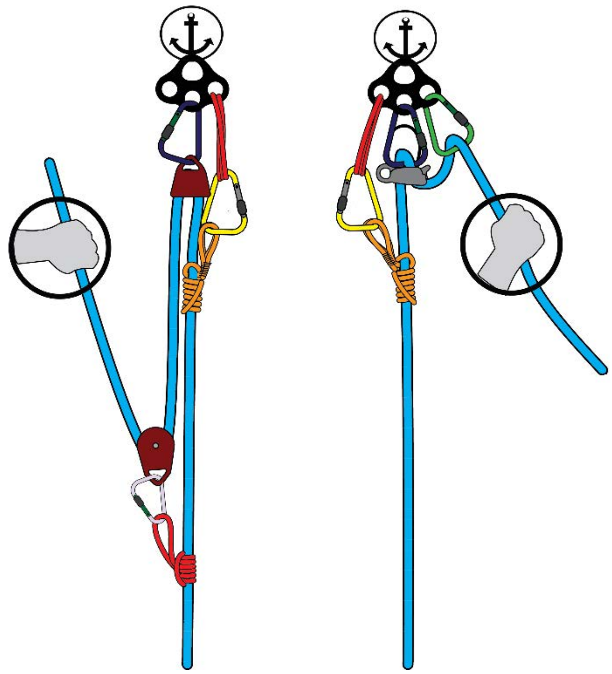


C. When haul system in constructed on both lines, inspect the system. Ready to raise.

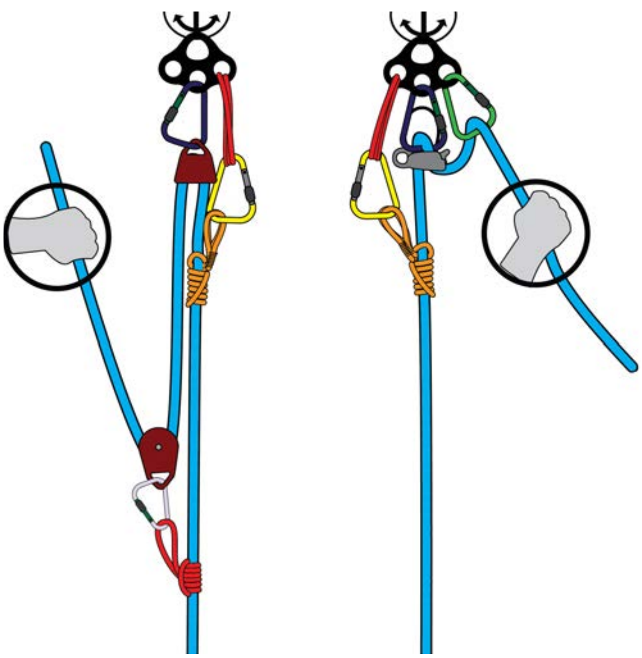
Raise to Lower Changeover ***(12.4-3A-D)***



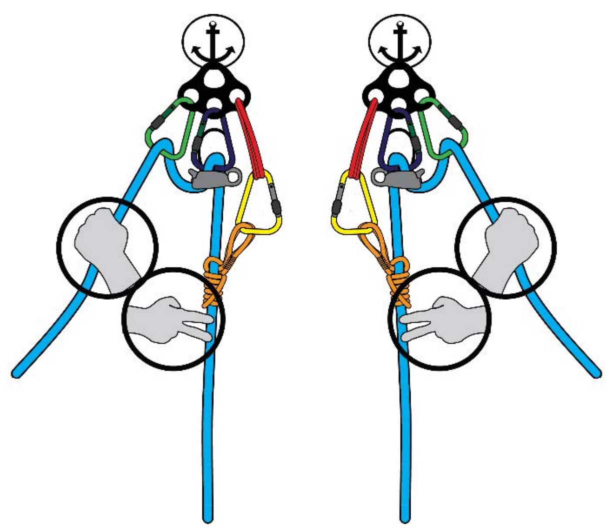
A. Hold on one mainline while the other hauls just enough to take the full load. You will have one tensioned mainline and the other will have a small amount of slack.



B. On the slacked line, make the prusik hand tight to the load. Disconnect the pulleys and haul prusiks from the slacked line. Insert the DCD. Never disconnect or open the VT prusik or it's carabiner.



C. Now that one line is changed over to lower, do a short haul to get the weight off the progress capture prusik on the haul line, then mind this while lowering out a short distance on the haul line. This will transfer tension onto the line that is set up for lower.

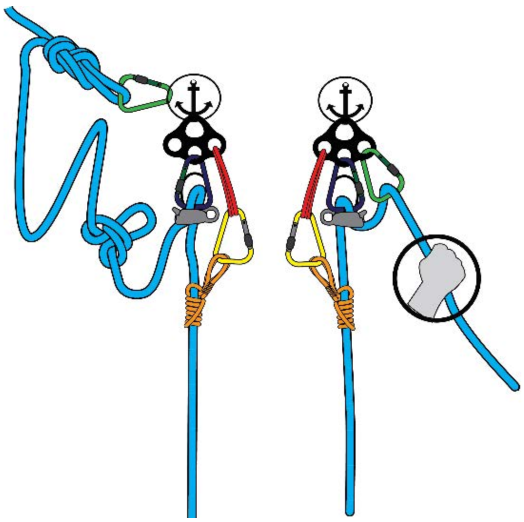


D. Now that tension is transferred, change over this remaining haul line to a lowering line. Inspect. Ready to lower.

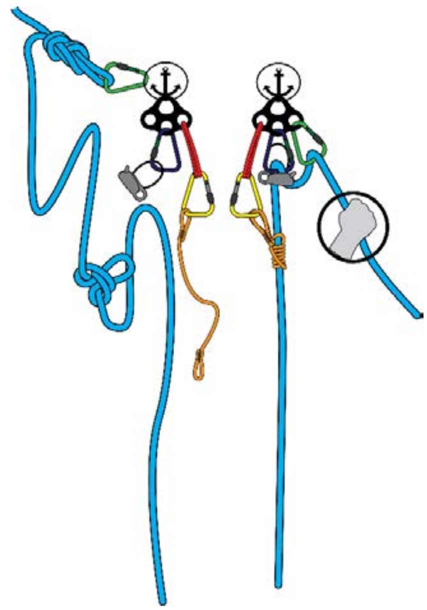
Component Based Knot Pass - Lower

This section will cover knot passes for a component based system. Knots are most commonly present when joining ropes together to form longer main lines. When possible, stagger rope lengths so the knots do not hit the DCDs at the same time. For example, on one line use a 300' rope first, then a 200' behind it. On the other line, use a 200' first with a 300' behind it. In this way, the team only has to pass one knot at a time.

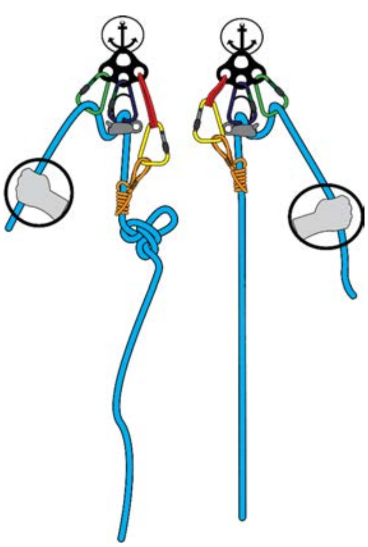
Staggered Knot Pass (12.4-4A-D)



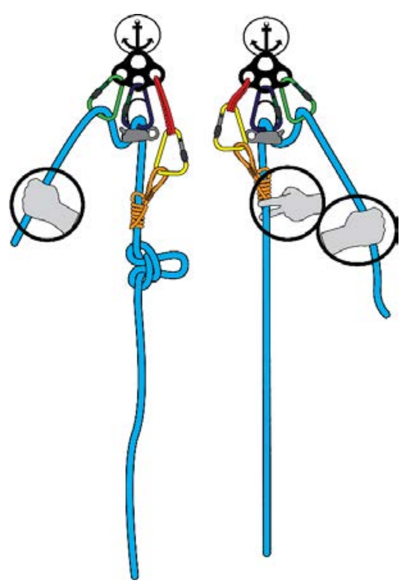
A. Tie a figure 8 on a bight and clip it to the anchor before disconnecting any equipment. Hold tension on the un-knotted line, slack the knotted line.



B. Disconnect the rope from the descent control device (DCD) in the knotted line.



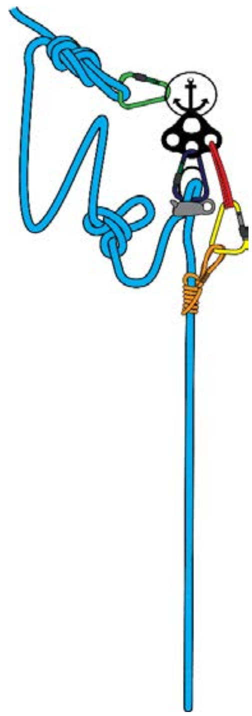
C. Reconnect the rope through the DCD and prusik with the knot on the load side. Inspect. Remove the backup knot.



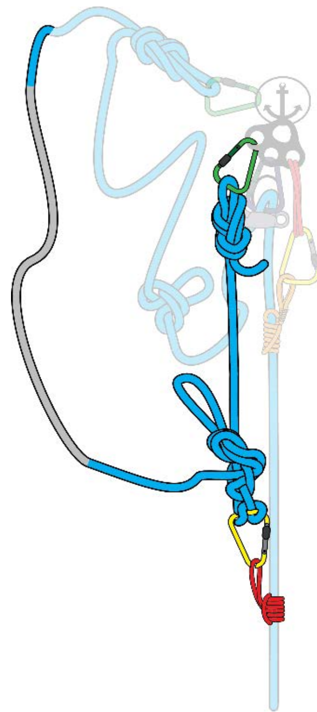
D. Lower slowly on the un-knotted line until both lines have

Simultaneous Knot Pass

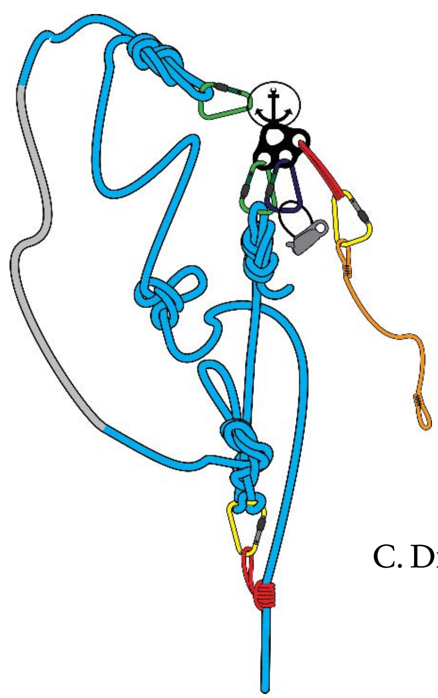
(only one rope shown for clarity, actions are performed simultaneously on both ropes)



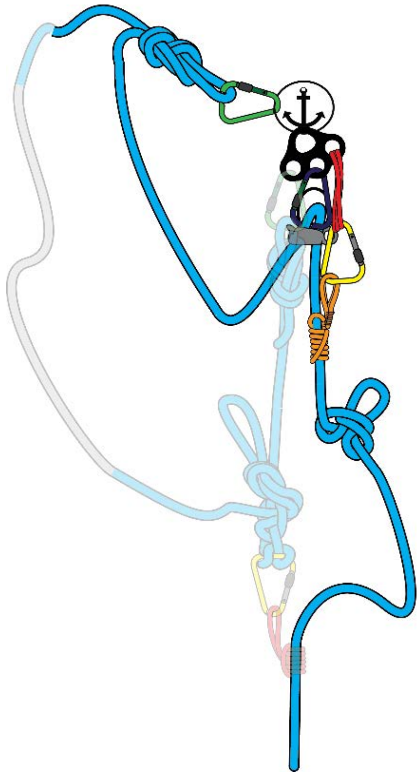
A. Tie backup knots on the running part of both ropes with enough slack to complete the knot pass.



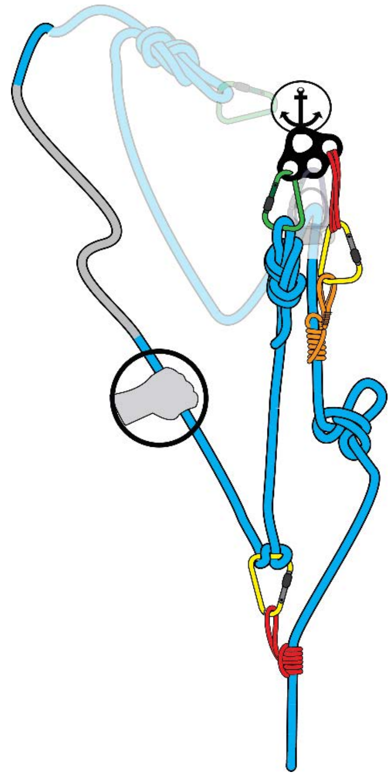
B. Attach a prusik on both mainlines on the working part of the rope. Use the tail of the rope to tie an Italian Hitch on a carabiner on this prusik. This makes a 2:1 tension transfer tool. Tie off with half hitch and overhand. DCD operators transfer tension onto this 2:1.



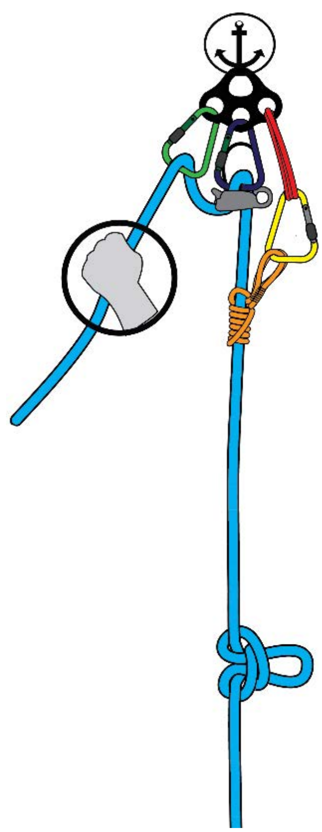
C. Disconnect the DCD and prusik.



D. Re-rig the DCD and prusik on the anchor side of the knot. Inspect. Hold.



E. Using the 2:1, transfer tension back to the DCD.



F. Ready to lower.

Component Based Knot Pass - Raise

Knot passes should be avoided during raise operations. The knot must be passed numerous times through the raising system, slowing the operation. If unavoidable, it is preferable to pass knots on one line at a time (similar technique to lowering: haul on one line to introduce slack in the other. Tie a backup knot in the slacked line. Pass the knot. Re-rig. Inspect. Continue the raise.) If simultaneous knot passes must be performed on both ropes, use the “slamma jamma” technique (Figure 12.4-2).

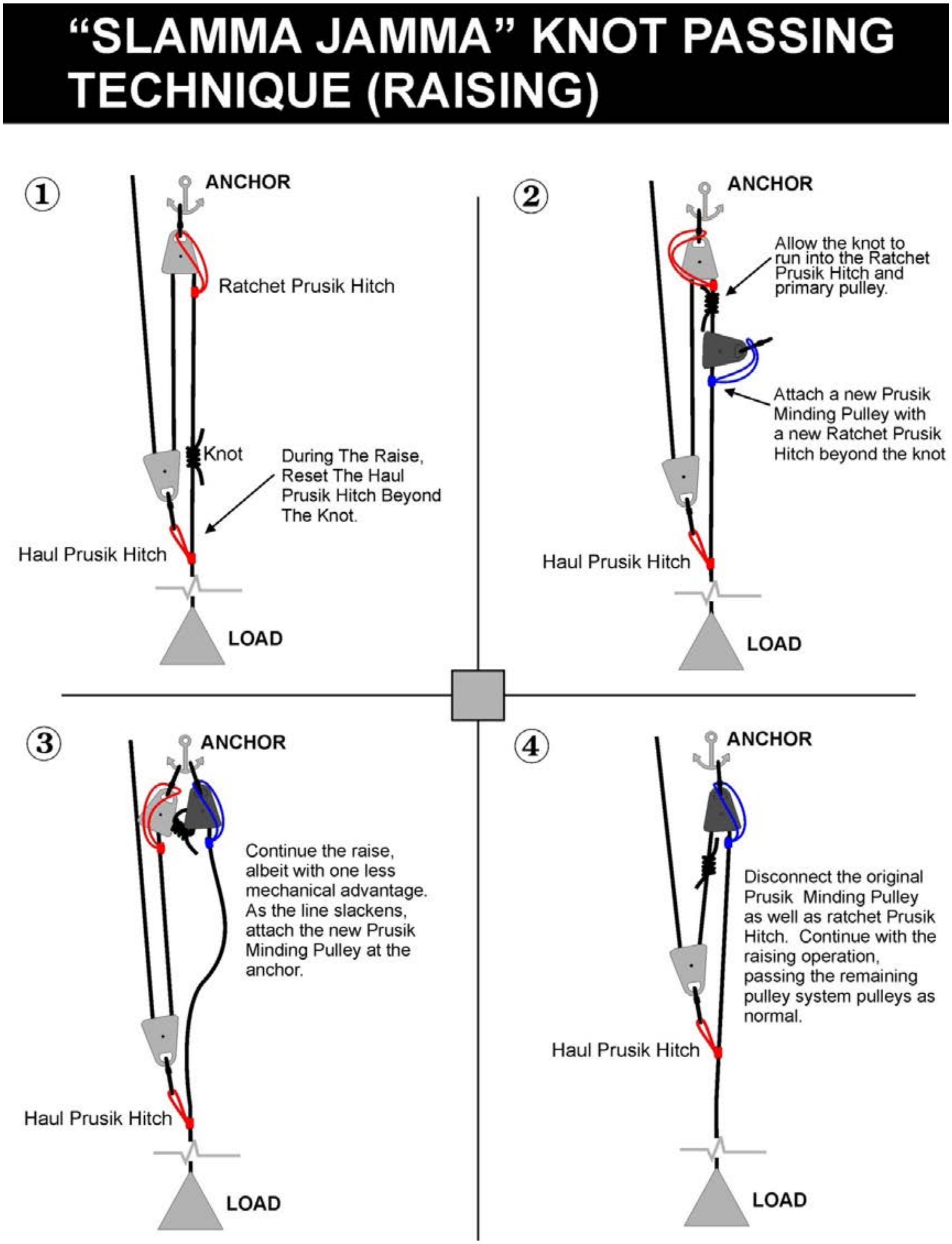


Figure 12.4-2 Component Based Knot Pass - Raise

12.5 PURPOSE BUILT SYSTEMS

This section will show how to perform lowers, changeovers, raises, and knot passes using purpose built equipment. The diagrams below depict the CMC Clutch™. However, other purpose built devices may be used such as the CMC MPD™, and Petzl Maestro™. This section is a basic overview. As with all rescue equipment, read and follow the manufacturer's detailed instructions.

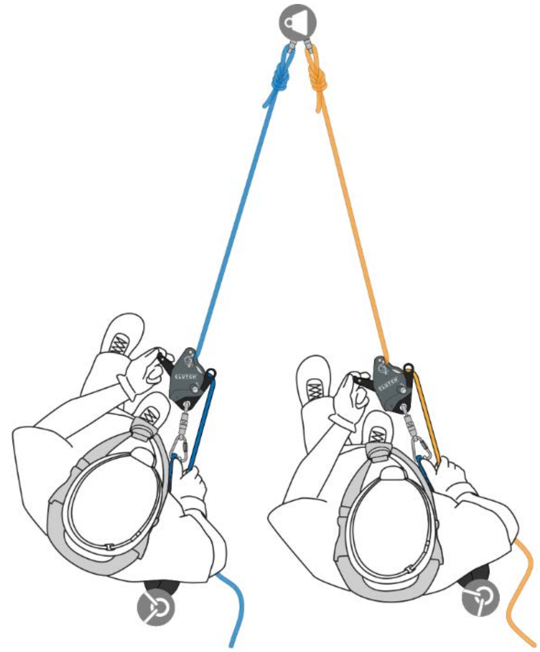


Figure 12.5-1 Two tensioned rope lower (CMC image)

Purpose Built System: Lower

The image to the right depicts a TTRS rope lower utilizing the CMC Clutch™ (Figure 12.5-1) . Note that the operators are standing behind the device for ergonomic position while holding the rope in its maximum friction position. Also note figure 12.5-2 depicts rigging a carabiner redirect for more friction. This also allows the operator to stand in a different position. The carabiner redirect should be utilized when the potential for more force exists; i.e., two-person loads and abrupt edge transitions.

Figure 12.5-2 Lowering with the Clutch; with carabiner redirect (left) and without carabiner redirect (center and right) (CMC image)

Purpose Built Systems: Rope Tailing

In many purpose built devices, to lower the load the operator must actively override the auto-stop feature of the device. There is a chance that the operator will not allow the auto-stop feature to arrest the load because of this manual override. To guard against this human factor, the ropes should be simultaneously tailed by a separate person and fed to the respective operators[31]. The Rope Tailer (Figure 12.5-3) becomes another active set of eyes and ears to monitor the actions of the respective device operators.

Figure 12.5-3 Rope tailer in a good, strong position and communicating with main line operators. Image by Kirk Mauthner.

Rope tailing techniques must be proven to work with no more than 0.1 kN force. The load must stop with no more than 1 m stopping distance. The person tailing the ropes must:

- Assume a strong stance.
- Concurrently grip and feed both ropes hand over hand.
- Know the specific requirements of the descent control devices being used in the lowering operation.
- Observe the operators of both systems and be prepared to detect and correct operator errors.

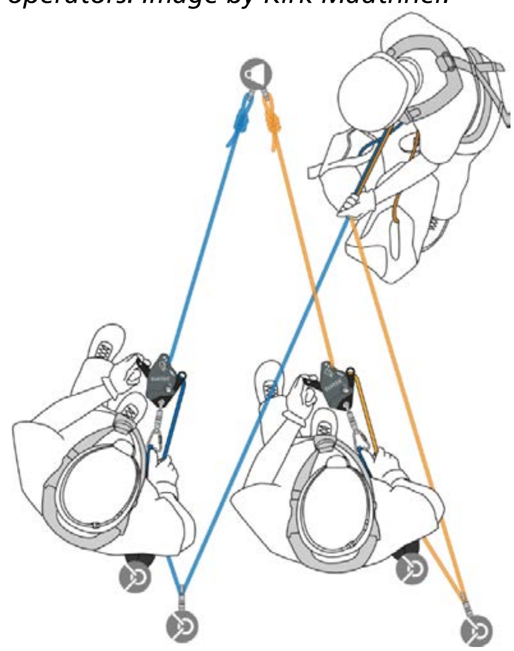


Figure 12.5-4 Rope Tailer (CMC image)

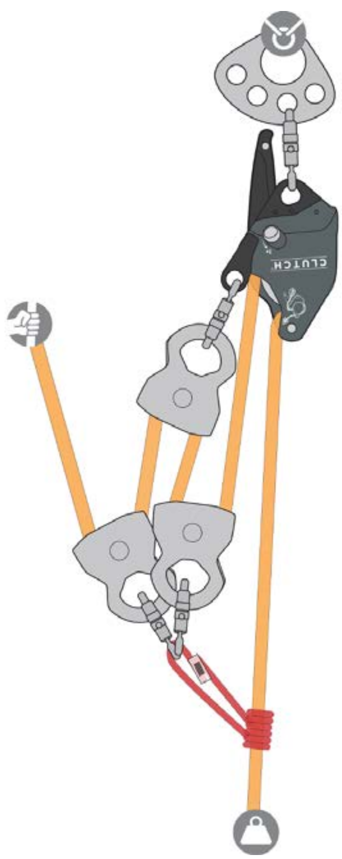


Figure 12.5-5 Raise (CMC image)

Purpose Built Systems: Raise

Raising operations and changeovers are strong suits of the purpose built device. The integrated pulley / auto stop allows for efficient hauling with no settling during resets as in prusik based progress capture. Refer to manufacturer instructions for the device you intend to use. Figure 12.5-5 shows the CMC Clutch rigged with a simple 5:1 mechanical advantage.

[31] Mauthner, Kirk. EMBC Rope Rescue NIF Equipment Testing 2016.

Purpose Built Systems: Changeovers

Purpose built devices make changeovers very simple. The images below show a lower to raise and raise to lower changeover using the CMC Clutch.

Steps for lower to raise changeover:

1. Set the release handle in the "stop" position.
2. Build desired mechanical advantage system.
3. Haul when ready.

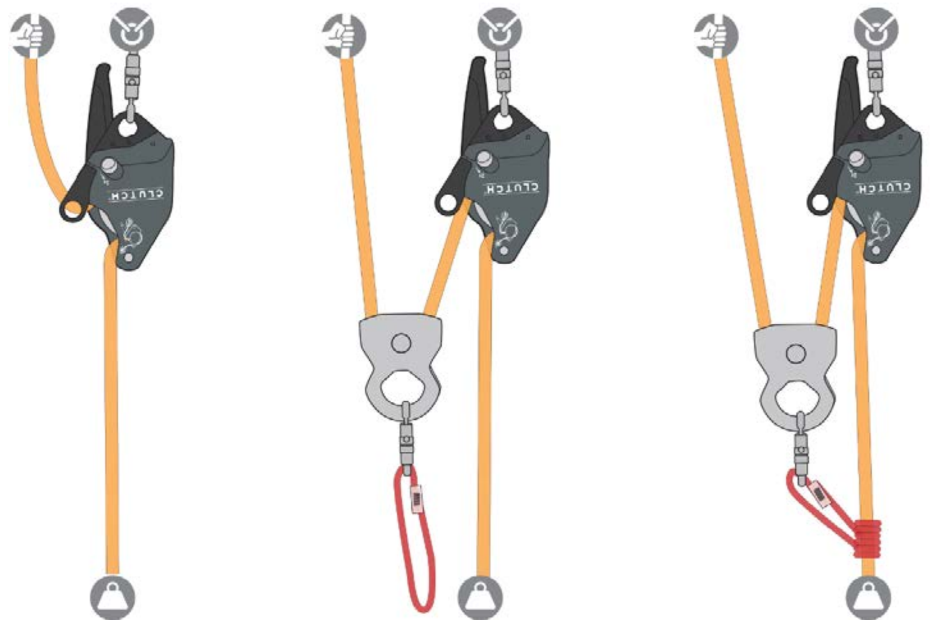


Figure 12.5-6 Lower to Raise Changeover (CMC image)

Steps for raise to lower changeover:

1) Ensure the release handle is in the "stop" position.
2) Remove mechanical advantage rigging.
3) Lower when ready.

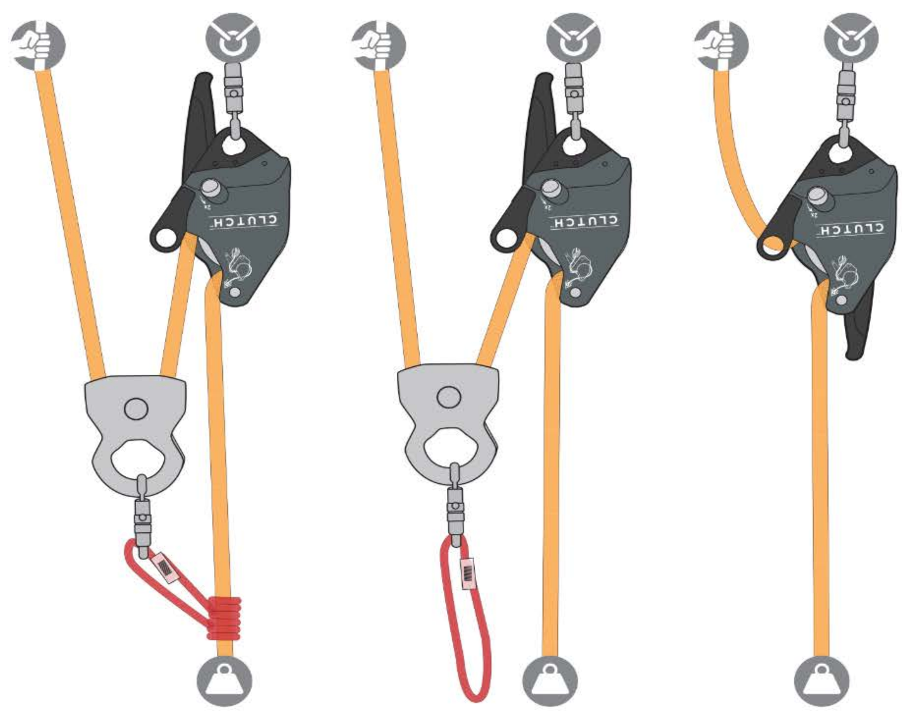


Figure 12.5-7 Raise to Lower Changeover (CMC image)

Purpose Built Systems: Knot Pass

Knot passes on purpose built systems are executed in a similar manner to component based systems. The following images demonstrate knot passes on only one rope using a CMC Clutch. If a simultaneous knot pass must be performed (knots in both ropes at the same time), this is done in a similar manner as shown in component based systems.

Steps for knot pass during lower:

1. Stop before the knot gets all the way to the device (leave 2 feet of slack).
2. Set both handles in the "stop" position.
3. Tie a backup knot in the rope behind the knot.
4. While holding tension on the other rope, slack the knotted rope, open the device, move the knot past the device, then re-rig the device. Take up slack and inspect.
5. Remove the backup knot.
6. Resume lowering, initially holding on the rope with the knot until tension is re-equalized between both ropes.

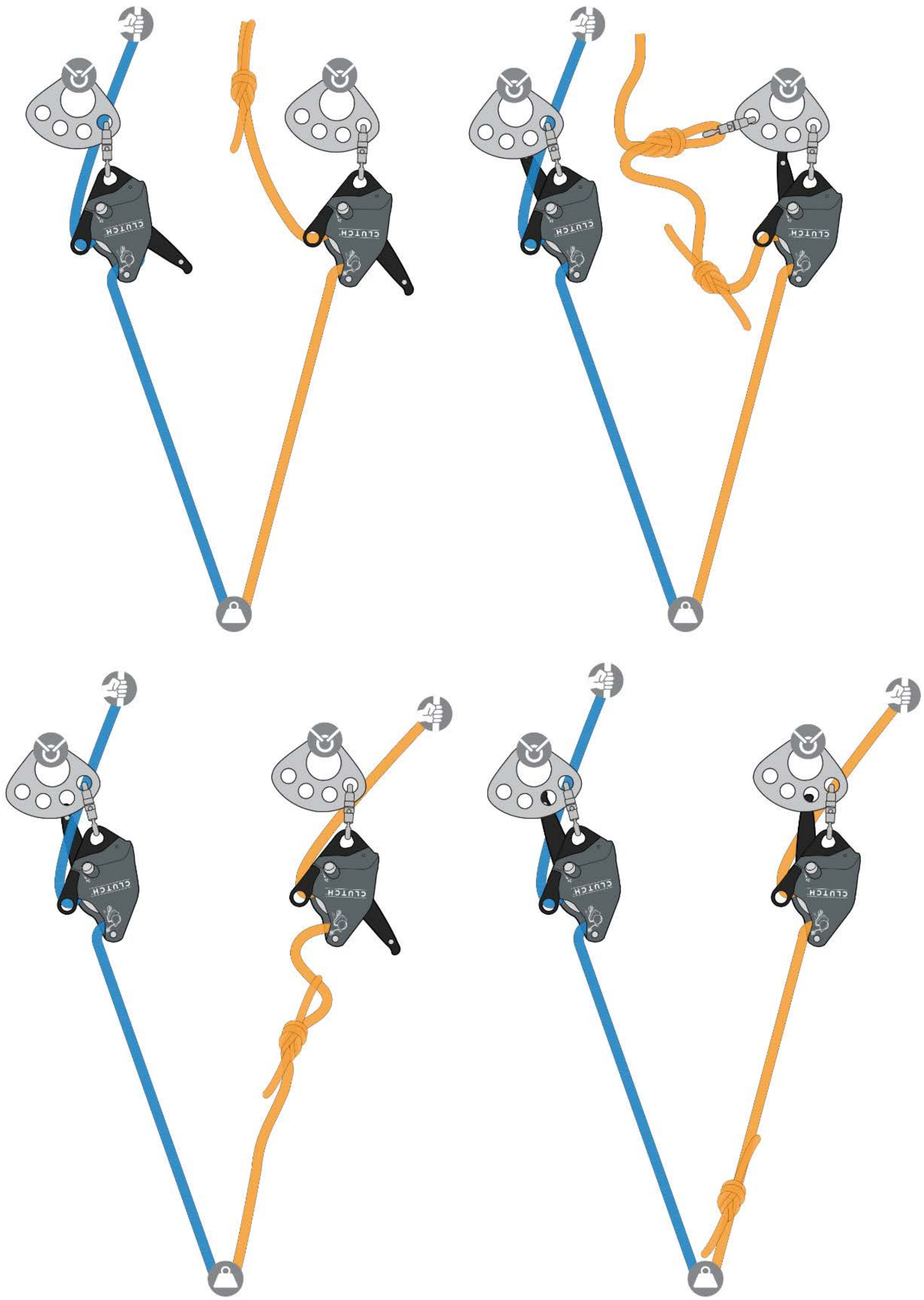


Figure 12.5-8 Knot Pass, Lower (CMC image)

Steps for knot pass during raise:

Note: knot passes should be avoided during raising operations. Knots must be passed through all pulleys and prusiks in the system, and the knot also constrains throw distances. This is tedious and time consuming. Another option is to “gang on” a system, but this also has disadvantages such as the necessity to continue progress capture on the initial rope. If a knot pass is unavoidable:

1. Raise until the knot is within 6 inches of the device. This will require moving the haul prusik around the knot.
2. Tie a backup knot in the rope behind the knot.
3. Continue hauling on the other rope until sufficient slack is introduced in the knotted rope (approximately 2 feet).
4. Move the knot to the other side of the device. Inspect. Remove backup knot.
5. Resume hauling.

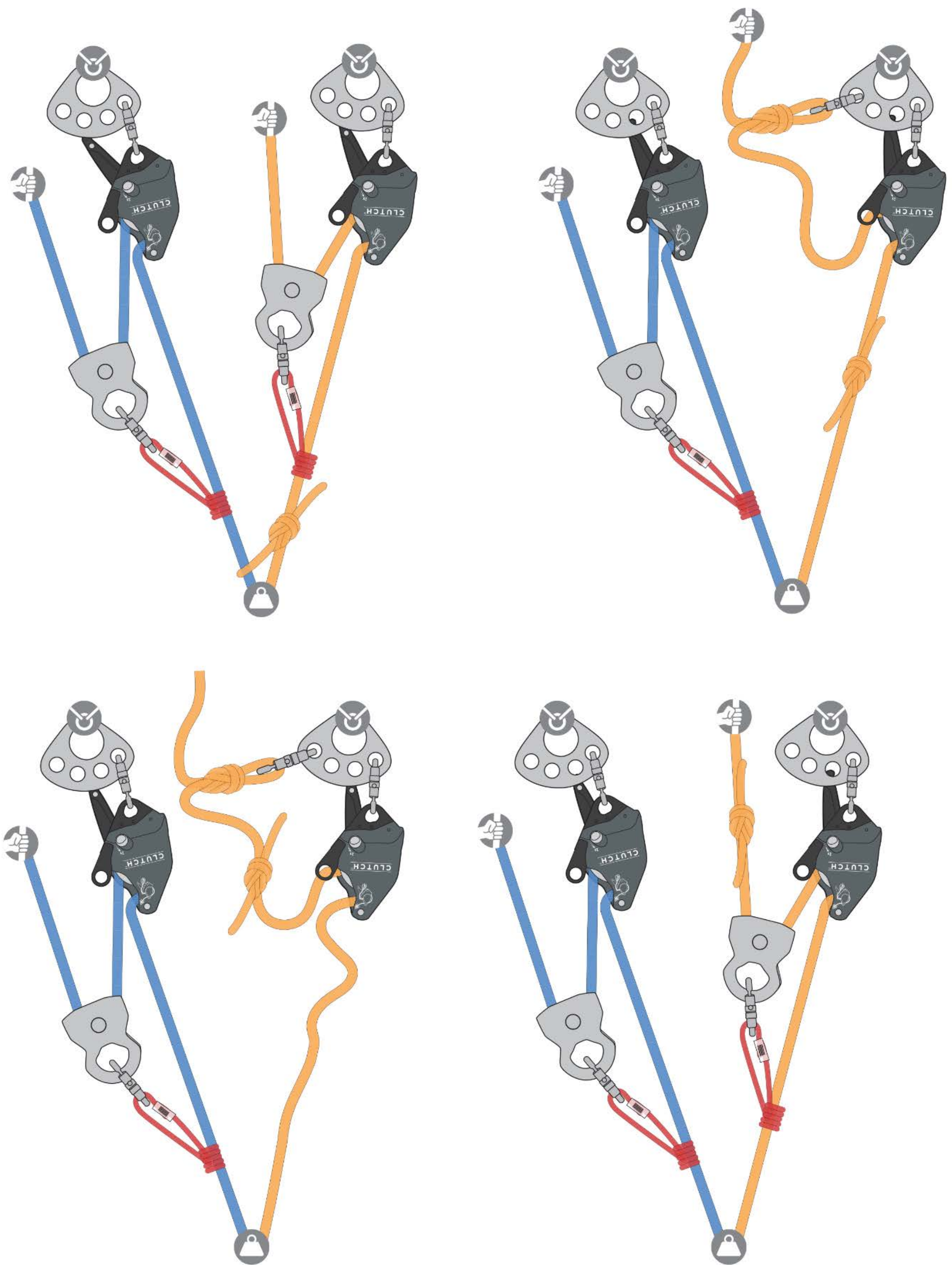


Figure 12.5-9 Knot Pass, Raise (CMC image)

13. PATIENT PACKAGING

13.1 PATIENT TIE-IN METHODS

Dependent upon their injuries, the patient should be fitted with a harness, helmet and eye protection for safety. In technical terrain the harness is an important element of patient packaging. If injuries would be aggravated by putting on a commercial climbing harness, then an improvised harness fashioned out of one inch tubular webbing or a specialized pick-off harness can be slipped into place on the patient with limited manipulation.

Figure 13.1-1 Patient packaging was an important consideration during this technical rescue on Half Dome at Yosemite National Park. NPS photo by Dave Pope.

PACKAGING REMINDERS

- Communicate with your patient—advise them of your entire evacuation plan.
- When employing a break apart litter, be certain the connection point is secure.
- Secure patient tie-ins to the lowest rail, which circumferentially wraps the patient creating more security and limiting movement. Avoiding use of the top rail prevents webbing from being abraded or cut by exposure against rock.
- Minimize direct compression from webbing on the patient's anatomy through padding, which could otherwise create compartment syndrome (pressure in confined body space) related injuries.
- Similar to splinting, recheck the patient's circulation following packaging.
- Prevent patient heat loss with insulation layers or external heat source.
- Utilize sufficient padding around the patient at rub points (e.g., shoulders, elbows and hips) along the litter rails.
- Provide a helmet and eye protection for the patient.
- Secure oxygen cylinders in the litter using a commercially manufactured padded carrier or other protected packaging. These must be completely secured for high-angle operations.
- When rescuers take breaks for water, food or personal relief, the patient should also be given such opportunities.
- Throughout the duration of their rescue, communicate often with your patient about how they are feeling and about what you are doing.

This section highlights a few patient packaging techniques which NPS rescuers have found very useful. This is not meant to be a complete collection of all known packaging techniques. Additionally, successfully packaging an injured subject routinely requires some level of improvisation based upon the unique circumstances of the incident (note the use of duct tape in Figure 13.1-1).

Figure 13.1-2 Yosemite litter packaging. Here the pre-existing manufactured cross-tie straps on the litter were incorporated in the patient packaging.

YOSEMITE LITTER PACKAGING
The Yosemite Litter Packaging technique is ideal for a patient not wearing a climbing harness, such as a trail carryout. This method utilizes several nylon runners to limit any patient movement inside the litter (Figures 13.1-2 and 13.1-3). Alternative packaging techniques, which lace the patient in with one extremely long runner, do not permit isolated adjustments or simple patient access without compromising the entire system. Use two 5.5 m (18 ft) runners for the "figure eight" wraps through the groin and over the shoulders (Figure 13.1-3). Finish with several additional circumferential cross straps (3.5 m / 12 ft), which secure the patient by locking them down in the rescue litter. These circumferential straps should be

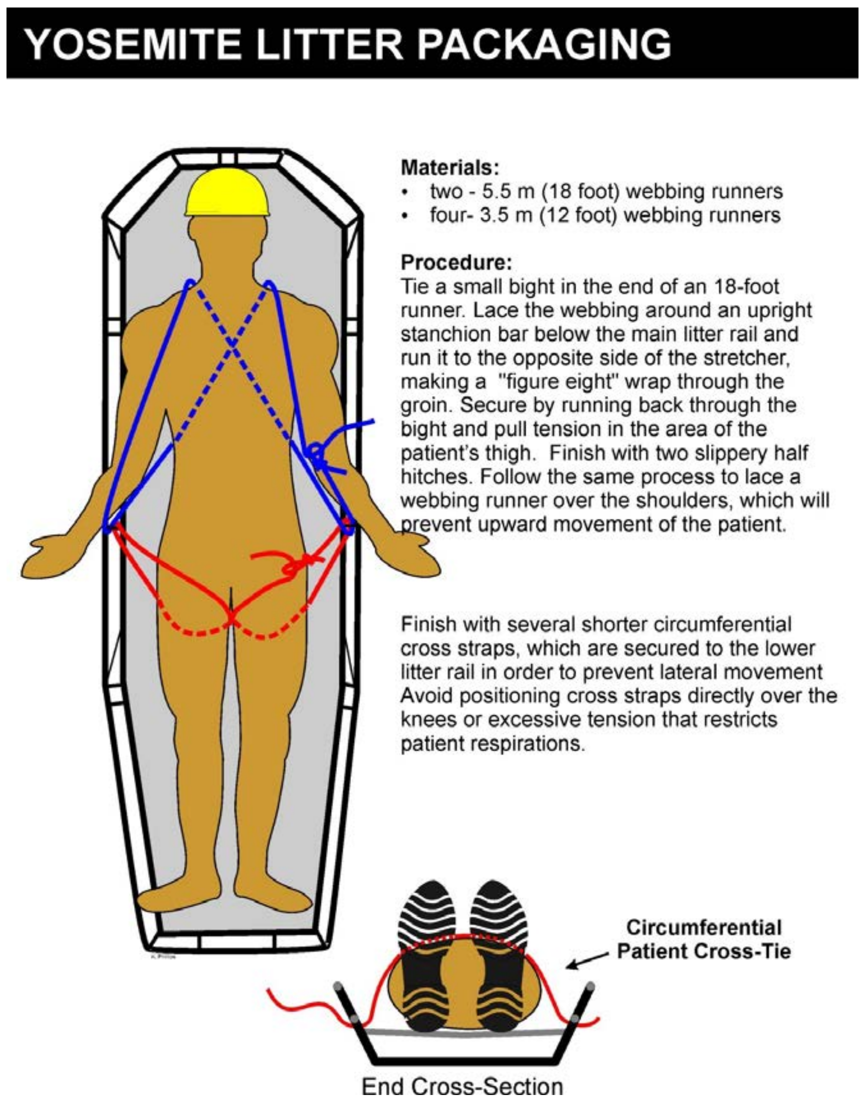


Figure 13.1-3 Yosemite Litter Packaging Technique.

secured to the lower litter bar in order to prevent any lateral patient movement. Avoid positioning cross straps directly over the knees or excessive tension over the torso that restricts patient breathing.

PURCELL PRUSIK TIE-IN

Three Purcell Prusiks can be quickly employed to secure a subject wearing a harness along the long axis of a litter (Figure 13.1-4). The initial foundation for this secure tie-in employs two Purcell Prusiks run through the subject's harness belay loop. These are inversely secured from one another to the litter in order to restrain subject movement toward the head or foot ends of the litter. The Purcells are then easily adjusted once in place to tension the attachments. A third Purcell is used to provide support to the feet.

Figure 13.1-4 Patient packaging with Purcell Prusiks. This provides an expedient technique for packaging a patient wearing a harness.

Alternate Webbing Method: Webbing runners can be employed in place of the Purcell Prusiks. Separate webbing runners are girth hitched at their mid-points to the harness belay loop. One runner is rigged toward the head and the other down toward the feet. Secure one end of each runner to an outside litter rail with a Clove Hitch or Round Turn with Half Hitches. Finish by tensioning and securing the other end of each runner around a litter rail on the opposite side of the litter with a Trucker's Hitch.

These patient tie-in procedures must be finished off with several lateral cross-ties to provide a complete and secure system. The numerous lateral cross-ties must suitably anchor the patient to prevent lateral movement or ejection.

FOOT LOOPS

Foot loops provide comfort for the patient, as they ease pressure generated by the suspension in a harness when employing a vertical litter orientation. If neither of the patient's legs is injured, the patient will feel like he or she can "stand" in the foot loops, thus easing the harness pressure. This is true to some degree even if the patient has one uninjured leg.

Rick Lipke of Conterra promotes a very secure "Leg Lash" method[32] (Figure 13.1-5). A 6 m (20 ft) piece of webbing is utilized for this tie. One end is secured to a litter rail below the knee and the webbing is wrapped around the outside of the opposite foot forming a loop. The webbing is laced around the far litter rail and then back down between the feet, capturing the webbing strand below the feet. The webbing is cinched tight and brought back to the starting point, where it is tied off. The remaining tail is run back through the point where the webbing strands form an "X" above the feet. The tail is cinched tight again and secured to the far litter rail. Lipke suggests the use of a chaffing pad (SAM Splint or slider rope guard) to protect the patient's knees during very steep operations.

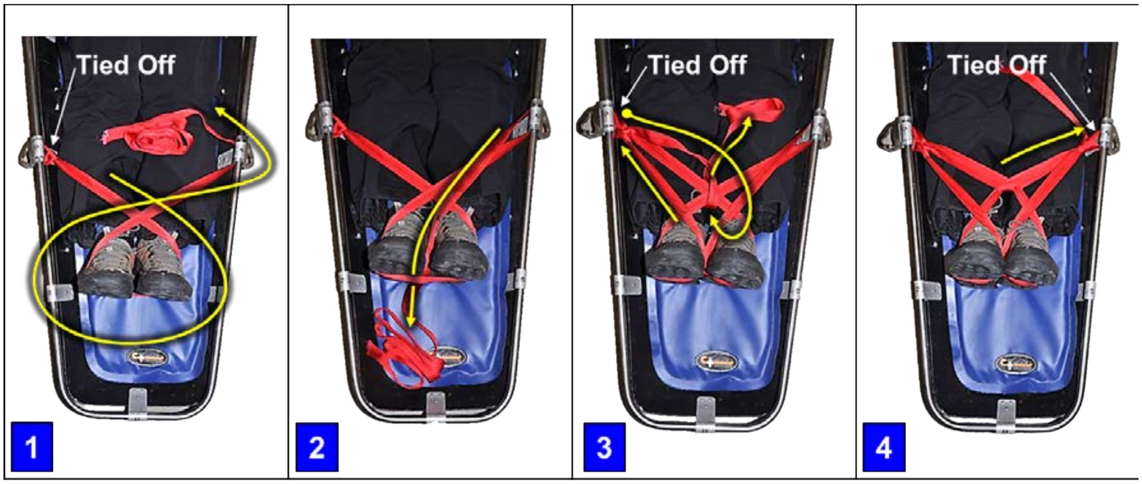


Figure 13.1-5 Conterra Leg Lash Technique.

A slightly less complicated alternative involves securing the feet with tied loops (Figure 13.1-6). The middle of a 3.6 m (12 ft) piece of webbing is located and then loops are sized around the patient's feet and secured with Overhand Knots. With the loops placed securely on the subject's feet, one webbing tail is anchored to a litter rail below the patient's knee. The other webbing tail is laced around the opposite litter rail and woven back through the short strand between the two tied loops. The webbing is cinched tight and secured adjacent at the anchor point of the first webbing tail.

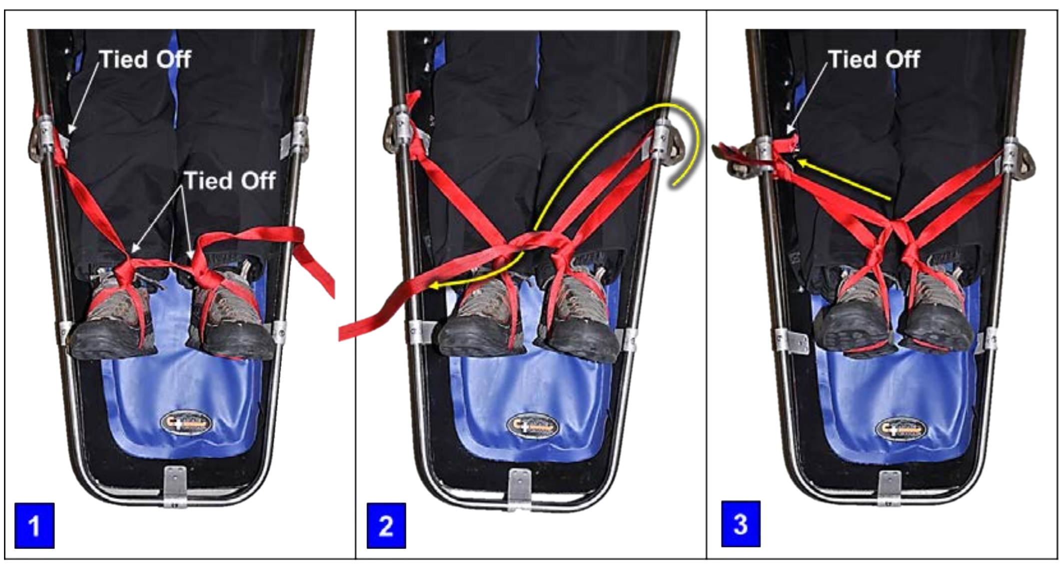


Figure 13.1-6 Foot tie-in with tied bights Alternate technique which employs individual tied bights around each of the patient's feet.

[32] Lipke, Rick. Technical Rescue Rigger's Guide. Second edition. pg. 110

13.2 PATIENT PADDING

Consider incorporating adequate padding in your packaging plan to create a comfortable nest for the patient during extended carry-outs. Extra time invested on the front end with effective packaging could prevent a miserable patient experience later. Beneath the patient provide thermal insulation as well as protection from rub points in the bottom of the litter using foam sleeping pads, a full-body Vacu-Splint, sleeping bags, or improvised material. Even in a warm environment, improvised patient padding can be constructed by rolling up sleeping pads longwise to make "Tootsie Roll" pads. These are secured in place along both sides of the patient and around their head to prevent contact with the litter frame in rugged terrain carry-outs. Consider padding potential rub points created by the patient ties on their clavicles, shoulders, hips and other areas likely to be sensitive to long-term compression. Avoid placement of tie-in straps directly over a patient's knees or neck and do not tighten chest straps in a manner that compromises breathing. Over the course of prolonged rescues, be diligent to check the condition of patient packaging at regular intervals, as it will tend to loosen, shift, or otherwise change. Patients will often communicate that something is rubbing or causing compression, but do not assume this is always the case and do not place this responsibility on them.

13.3 LITTER FACE SHIELD

A litter face shield can be utilized with a litter to provide the patient with protection from rockfall, inclement weather, and even the spray from waterfalls. The CMC Rescue Litter Shield is constructed of Lexan® and is available in a standard or "plus size" (Figure 13.3-1—1 & 2), which provides clearance for a spinally immobilized patient as well as better access for patient care. Weight of the standard shield is 1.4 kg (3.08 lbs).

The Guardian Litter Shield, manufactured by Cascade Rescue, retracts like a convertible car-top for storage and remains with the litter (Figure 13.3.1—3). This litter shield also provides excellent protection from rockfall and weather and a debris skirt extends to the lower litter rail providing additional protection. The Guardian Litter Shield is constructed of Cordura, Kevlar, Nylon and Spring Steel over a Stainless perimeter and weighs 4.5 kg (10 lbs).

Most commercially available face shields can be attached to most rigid-frame litters, and then removed again when not needed. Several different quick attachment methods exist, including clevis pins, Velcro straps, or a combination thereof.

Face shields offer added protection from falling objects, but they do not take the place of a helmet worn by the patient. If the patient's injuries permit the placement of a helmet on his or her head, one should be provided to them and used in conjunction with a face shield.

Figure 13.3-1 Litter Shields. 1. CMC Rescue Standard Litter Shield 2. CMC Rescue Litter Shield Plus 3. Cascade Rescue Guardian Litter Shield. ©CMC Rescue and Cascade Rescue.

14. RESCUE LITTER

14.1 INTRODUCTION

Rescue litters provide a secure transport device in rugged environments. Evaluate the need for the deployment of a litter in a technical rescue. A patient with minor injuries in exposed technical terrain may be more easily evacuated in a harness than a litter.

Selection of the proper model of rescue litter for a rescue team should include an evaluation of the environment it will be used in as well as the compatibility with patient packaging adjuncts (vacuum mattress, traction splints, etc.) and other related accessories including the litter wheel.

Titanium and Stainless Steel Litters

Titanium and stainless steel litters are the most common in technical rescue (Figure 14.1-1). They are light, strong, and durable. Titanium is lighter than stainless steel but more expensive. Litters with a break-apart design facilitate easier transportation of the device to an inaccessible accident site due to its ability to be strapped to a backpack. A litter with a tapered design of the lower leg section allows the lower section to easily nest in the upper section for storage. Rectangular (non-tapered) models provide more space, but they are heavier and more bulky.

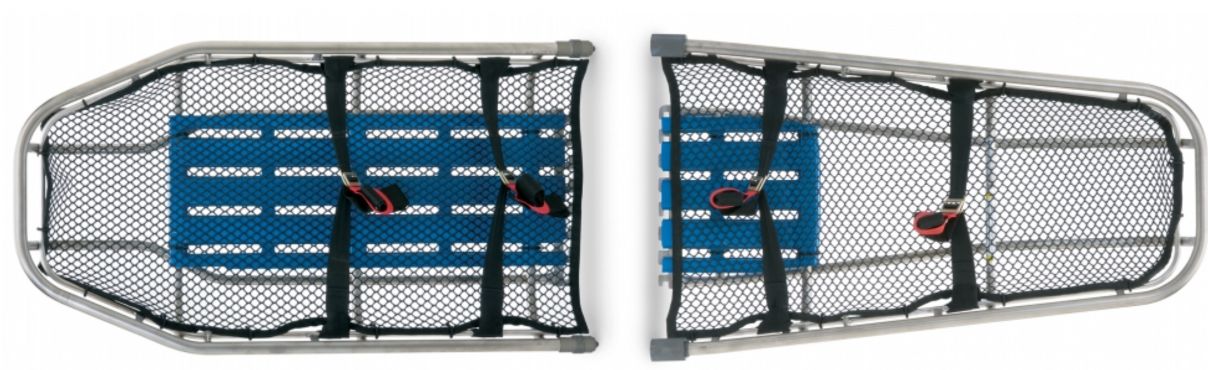


Figure 14.1-1 CMC Titanium Split-Apart Rescue Litter. 7.3kg (16 lbs)

Fiberglass Litter

Fiberglass litters are constructed with a composite fiberglass shell, which is a lightweight and extremely strong material. The solid shell design provides increased patient protection during transport through brush and snow, but fiberglass is less durable against rock than titanium and stainless steel (Figure 14.1-2).

Figure 14.1-2 Fiberglass litter. Cascade Rescue Advanced Series Model 200 Litter. Weight 11 kg (25 lbs). © Cascade Rescue.

Plastic Litter

Plastic litters are basket-style litters constructed with a solid high-density polyethylene shell that is encircled with a tubular rail for structural integrity (Figure 14.1-3). This litter works well for vertical and steep angle rescue applications. Models designed with a smooth bottom slide easily over snow and rock scree.

Figure 14.1-3 Rigid plastic litter. Junkin model 200B, which weighs 14 kg (32 lbs). © Junkin Safety Appliance Company.

Available models include a break-apart design to facilitate transporting the litter to a remote rescue scene via backpack. The top rail is used for attachment of a litter harness, steep-angle lines, and as a location to grasp during carryouts. The lower rail provides rigidity to the "roll cage" body during technical evacuations. Do not leave such a litter exposed to harmful ultraviolet rays for extended periods, since the plastic will deteriorate, fade and become brittle with exposure.

Sked

The Sked Litter (Figure 14.1-4) is a compact and lightweight polyethylene plastic litter based upon the design for a game "drag sheet" used by hunters. Although this litter slides easily over obstacles and snow it provides no impact cushioning for the patient. This design excels in confined spaces. However, it circumferentially squeezes a patient when they are fully packaged, and permits only limited patient care access during transport.

Figure 14.1-4 Sked Litter. Weithg 7.7 kg (17 lbs). © Skedco.

For spinal immobilization, the manufacturer, Skedco, recommends it be used with their proprietary immobilization device, the Oregon Spine Splint, which is very similar to a KED. Rigid, padded cross-boards can be purchased with the Sked and placed under the patient perpendicular to the long axis of the Sked, which will somewhat reduce the circumferential squeeze of the Sked. Pre-sized, load bearing webbing straps and a pre-sized, cut-to-length section of 11 mm static rope also come with the Sked and allow it to be utilized in vertical raising and lowering operations, in both the horizontal and vertical configuration, as well as helicopter hoist or short-haul operations.

The entire Sked litter is rolled for storage in a backpack and the complete kit weighs 7.7 kg (17 lbs). When rolled up tightly, the Oregon Spine Splint can be inserted into the hollow space inside the Sked carrying backpack, which keeps both devices ready and available in one place. The webbing straps, static rope length, and a few carabiners can be stored in external zippered pockets on the Sked's carrying backpack.

Traverse Rescue Stretcher (TRS)

This lightweight wraparound stretcher is another design that is useful for high angle, confined space rescue and remote backcountry rescues. Like other wraparound stretchers, the narrow profile permits it to be directly loaded aboard a confined Helicopter Emergency Medical Services (HEMS) helicopter. The TRS (Figure 14.1-5) is constructed with an inner high density polyethylene sheet, which is covered with 1,350 denier Cordura nylon outer layer to resist abrasion and an inner layer of 1,000 denier Cordura to provide for patient comfort. Carry handles and lift attachment points are constructed with two-inch webbing that serve as structural attachment points for a lifting harness. Carry handles are fitted with plastic tubing for easier carrying. The full body adjustable patient harness is color coded and secures the patient without the need to fold over the head and foot ends of the stretcher. The stretcher is designed for vertical or horizontal use. Weighs 8 kg (18 lbs).

Figure 14.1-5 The lightweight Traverse Rescue Stretcher employs a wraparound design. Weight 8 kg (18 lbs).

14.2 LITTER HARNESSES AKA BRIDLES

The litter harness permits rigging of the litter in a horizontal or vertical orientation for technical raising and lowering operations with an attendant to guide the litter and provide limited patient care. A variety of commercially manufactured litter bridles are available, with a "God ring" sewn directly into the webbing itself. Many of these are designed to be adjustable when tensioned using load-rated camming buckles. It is possible to change the head or foot end of the litter for terrain obstacles and patient care.

Carabiners used to connect the litter harness to the litter are rigged with the gates down and facing inward. It is preferable to pre-rig a litter harness in advance and keep it stored in a stuff sack attached to the litter rather than improvising one on scene. Fixed-leg systems have several advantages over improvised systems, such as: 1) They are often lighter-weight and more streamlined due to not needing adjustable buckles or bulky Prusiks knots and, 2) speed of rigging is increased because no harness adjustments are necessary. One disadvantage of commercially made fixed-leg systems, though, is they are typically more expensive than improvised, "homemade" bridle systems.

Figure 14.2-1 Conterra Fix Litter Harness, ready to attach to litter.

A fixed leg litter harness can be constructed with webbing to optimal leg lengths, or several models are available commercially that are pre-sewn (example: Figure 14.2-1). Employ contrasting colors of webbing for the head and foot sections, and utilize "red to head" to reduce the likelihood of human error during rigging at a scene.

Figure 14.2-2 Conterra Fix Litter Harness, attached to litter.

Conterra Fix Litter Harness

The Conterra Fix Litter Harness employs the concept that a properly designed litter harness does not have to have infinitely adjustable legs to be versatile. The apex of the harness was designed for weight savings and rigging versatility and uses a large, upper triangular hole that allows ample room for multiple carabiners or ropes to be tied directly in. Extension straps are sewn directly into two lower, smaller holes below the main triangle rope attachment hole, and have triangular screw links on their opposite ends that attach to the head-end and foot-end harness straps. A third lower, smaller hole provides a quick, easy attachment for an extra secondary safety point for either the patient or the attendant (Figures 14.2-1 and 14.2-2).

The Fix Litter Harness will fit most litters shown in this chapter. The center yellow extension straps can be re-configured, offering a range of lengths to the straps (Figures 14.2-3 and 14.2-4), and it works in a variety of applications, such as vertical cliff, confined space, or helicopter hoist/short-haul operations. The harness can be split in half using only the head-end straps and a 4:1 jigger for the foot-end (Figure 14.2-5), conversely both ends can be used independently (not attached to the yellow extension straps and large triangular main attachment point) for twin pulley Kootenay Highline operations (Figure 14.2-6). It weighs 565 g (20 oz), has a breaking strength in standard configuration of 36 kN, and comes with a storage pouch that attaches to the litter rails.

Figure 14.2-3 Conterra Fix Litter Harness, attached to litter, using included extension straps (Note: Second mainline omitted for figure clarity).

Figure 14.2-4 Conterra Fix Litter Harness, attached to litter, without using included extension straps (Note: Second mainline omitted for figure clarity).

Figure 14.2-5 Conterra Fix Litter Harness, attached to litter, using included extension straps, "red to the head" straps, and a 4:1 jigger for the foot-end attachment in lieu of the included foot-end straps.

Figure 14.2-6 Conterra Fix Litter Harness, attached to litter, split in half for twin pulley Kootenay Highline ops.

14.3 LITTER RIGGING

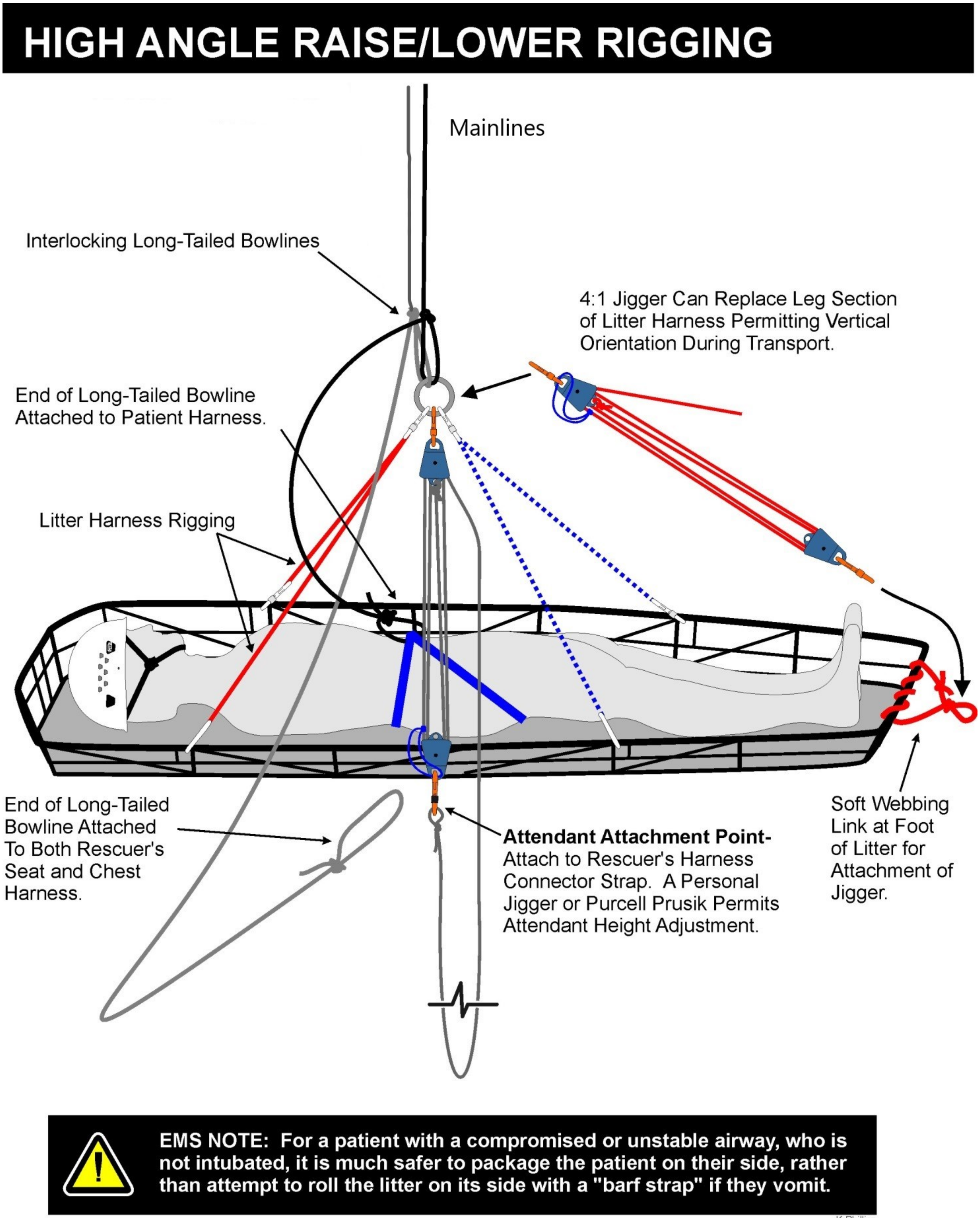


Figure 14.3-1 Litter rigging schematic for raising/lowering operation

4:1 LITTER/ATTENDANT JIGGER SYSTEM

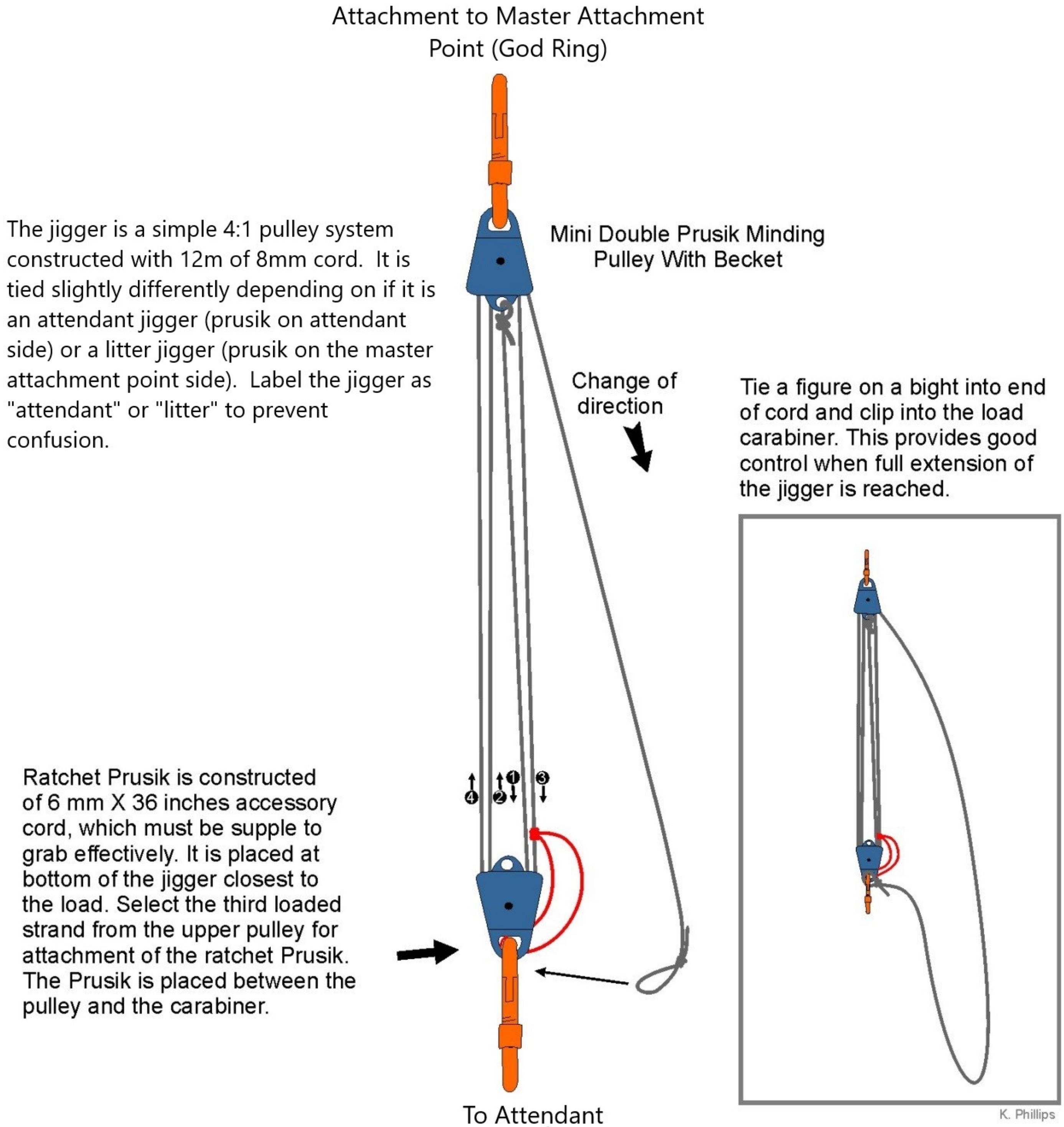


Figure 14.3-2 Jigger construction for attendant jigger

UPPER ATTENDANT POSITION FOR HIGH ANGLE RAISE/LOWER

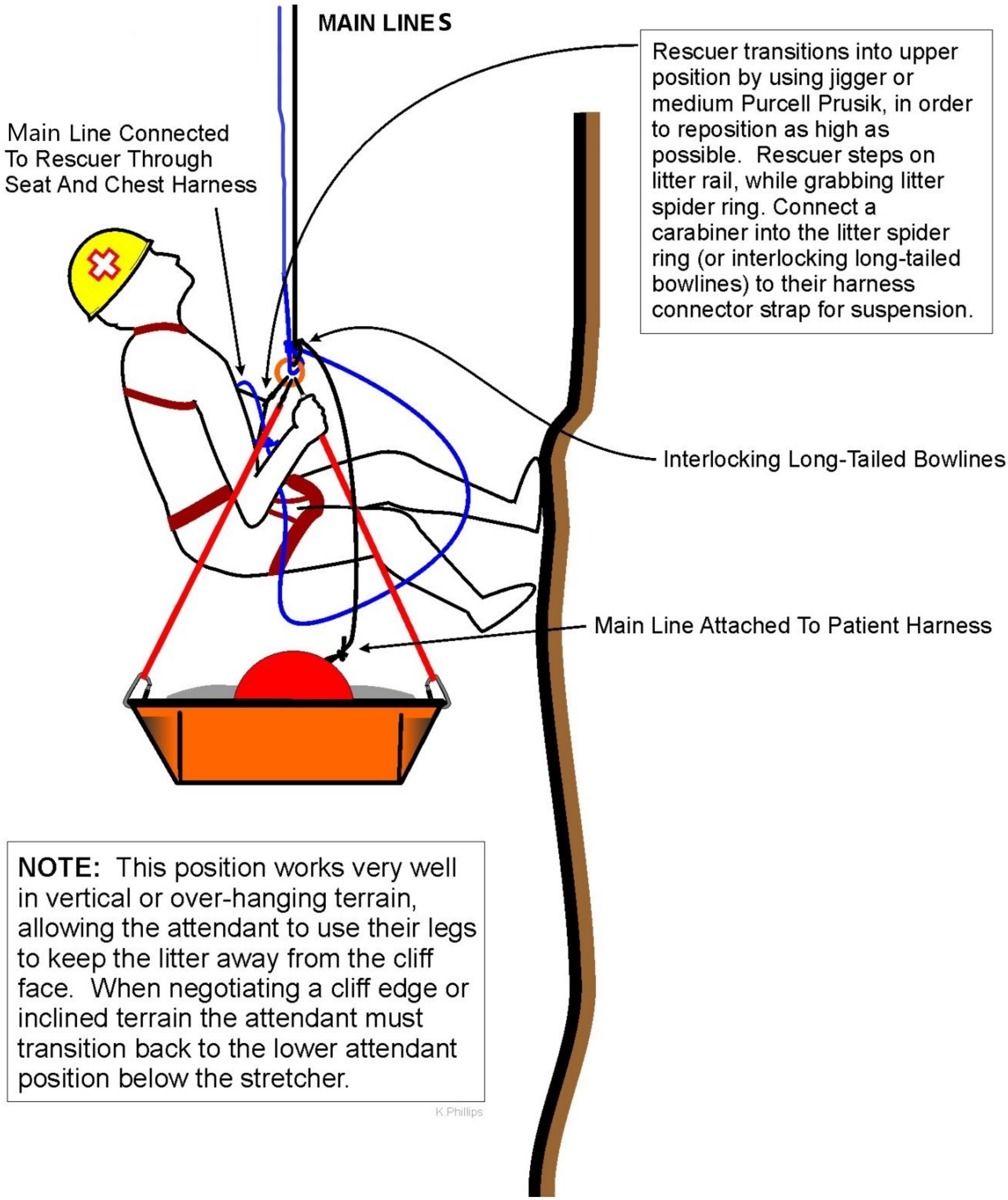


Figure 14.3-3 Upper Attendant Position

Figure 14.3-4 Horizontal litter orientation with lower and upper attendant positions

Figure 14.3-5 Vertical Litter Lowering. The attendant straddles the litter during this vertical litter edge transition.

The challenge of negotiating a loaded litter over a sharp cliff edge without the benefit of an artificial high directional is best accomplished with the litter in a vertical orientation. The attendant straddles the litter at the waist level of the subject and slowly slides the litter over the ground as they back over the cliff edge in a controlled manner (Figure 14.3-5). The attendant will lean back to keep their tether under tension. However, they must be mindful to pull the litter in order to keep the litter bridle under tension till beyond the tip point at the cliff edge.

To facilitate a smooth transition over the cliff edge, the edge attendants can assist the litter attendant by vectoring the main line. This maneuver involves the edge attendants positioned, if feasible, on either side of the main line near the cliff edge. With the litter attendant positioned directly at the cliff edge, the edge attendants then lift the mainlines directly upward (Figure 14.3-6). This needs to be a well-choreographed movement, and once the main lines becomes vectored the attendant will lean back and a command for "down slow" will follow. The vector will then be released slowly. The goal is to make this a fluid maneuver. Vectoring is fatiguing and lowering delays should be avoided. Figure 14.3-7 below lists standardized communications for technical rescue operations.

Figure 14.3-6 Vectoring the mainline. The vectoring maneuver with the mainline should be no higher than waist height off the ground.

14.4 PIKE AND PIVOT TECHNIQUE

AKA VERTICAL LITTER EDGE TRANSITION TECHNIQUE

Attempting to raise a loaded litter in a horizontal orientation up over a sharp (90°) cliff edge, without the benefit of an artificial high direction, can quickly result in "edge trauma" to the patient. During such a maneuver the inside rail of the litter will have a natural tendency to catch on the edge of the cliff and cause the loaded litter to roll inward against the rock face. Orienting the litter in a vertical orientation is part of the solution. In raising with a vertical orientation, the head of the litter may become jammed against the cliff edge by the hauling system. This can be overcome with good litter attending, but in some cases with a sharp overhanging edge, the pike and pivot technique in necessary. The Pike and Pivot (Vertical Litter Edge Transition Technique), also referred to the "V-Strap Technique," is an excellent procedure for negotiating a sharp edge on a raise without the benefit of a high directional.

To accomplish the maneuver, the litter is placed in a vertical orientation below the lip by the attendant during the raising operation. The raising is halted when the knots at the master attachment point (long-tailed interlocking bowlines) just reach the edge protection at the cliff edge. This position places the loaded litter a few feet below the cliff edge. A pre-rigged V-strap, which is constructed from a ten meter section of 8 mm cord or one-inch tubular webbing, is put in service. The V-strap has a small bight knotted at the middle of the cord with locking carabiners attached to bights placed at each terminus of the cord. The ends of the V-strap are lowered down to the attendant and the V-strap is attached to the outside of the litter at the patient's mid-thigh or knee level. If possible, the connections to the litter should be made directly to a stanchion that is oriented horizontally in order to prevent excessive torque on the carabiners. When the V-strap is lowered, make sure it is positioned underneath the mainlines.

To avoid trapping the belay line during a Pike and Pivot Maneuver, position the V-strap under the main lines before attaching to the haul system.

The forward part of the pulley system on one of the main lines is detached from the haul Prusik Hitch and transferred over to the bight on the upper end of the V-Strap. The other mainline will become a belay line for the final raise. At this point the section of the main line, which comes off the head end of the litter will become "dead" and go slack during the final raise. An option is to add an additional Prusik Hitch on the opposite side of Prusik-Minding Pulley containing the ratchet Prusik Hitch to thoroughly deaden this section of line. This action locks the main line in place in front of the hauling system. However, it is possible to conduct the final raising maneuver without this additional Prusik. The hauling system, in this case a 5:1 simple system, becomes reconfigured to a 4:1 simple system for the short final raise (Figure 14.4-2).

LOWER	
ROLE CALL - "ALL QUIET!"	If not ready, reply: "Standby _ minutes"
Team Lead / Control	**Operator Response**
“Blue Rope ready?”	“Blue Rope ready.”
“Red Rope ready?”	“Red Rope ready.”
“Rope Tailer ready?” (if applicable)	“Rope Tailer ready.”
“Edge ready?”	“Edge ready.”
“Attendant ready?”	“Attendant ready.”
EDGE TRANSITION BRIEFING	
Control explains edge transition movements.	
Control conducts dry runs with commands as needed.	
LOWERING OPERATION	
Team Lead / Control	**Operator Response**
“Attendant, approach the edge.”	“At the edge.” (positioned for edge transition)
“Tension all lines."	“Blue Rope ready, “Red Rope ready.”
“Attendant, lean back.”	Attendant leans back, weighting the system.
“Edge, vector.”	Edge holds ropes at waist height, assists in transition.
"Down slow"	Lower smoothly through the edge transition
"Down Slow, Down Down, Slow Slow, Stop"	Attendant commands
"All stop, on the ground"	The litter and attendant are on the ground

Figure 14.3-7

RAISE	
ROLE CALL - "ALL QUIET!"	If not ready, reply: "Standby _ minutes"
Team Lead / Control	**Operator Response**
“Blue Rope ready to raise?”	“Blue Rope ready.”
“Red Rope ready to raise?”	“Red Rope ready.”
“Edge ready?”	“Edge ready.”
“Attendant ready?”	“Attendant ready.”
EDGE TRANSITION BRIEFING	
Control explains edge transition movements.	
Control conducts dry runs with commands as needed.	
RAISING OPERATION	***MA on both ropes***
Team Lead / Control	**Operator Response**
"Attendant, on your call"	Attendant calls commands: "up slow, stop, etc..."
"Up slow"	Haul slowly
"Slow, slow"	Slower
"Up, up"	Faster
"STOP"	Stop
"All stop"	Once litter and attendant cross the safety line

Figure 14.3-7 cont’d.

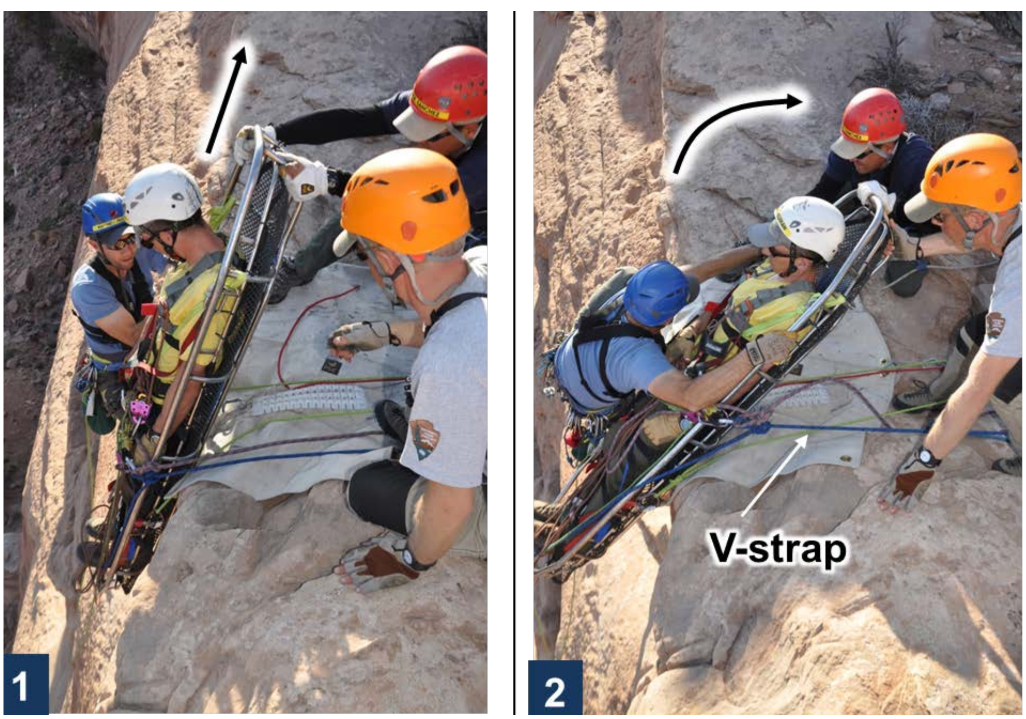


Figure 14.4-1 Photo sequence of pike and pivot maneuver.

After the V-strap is connected, the attendant needs to move their attachment to a side rail of the litter or climb up to the top of cliff out of the way using the side rail supports as a ladder. As the V-strap is pulled, the litter will raise with the head end doing a “pike” into the air above the cliff edge (Figure 14.4-1). The litter attendants may need to push the litter out from the wall to clear any obstacles. Once the head of the litter is raised up above the lip of the edge, the edge personnel then simply grab the head end of the litter and "pivot" it toward them. The litter is now located on top without a struggle or trauma to the patient.

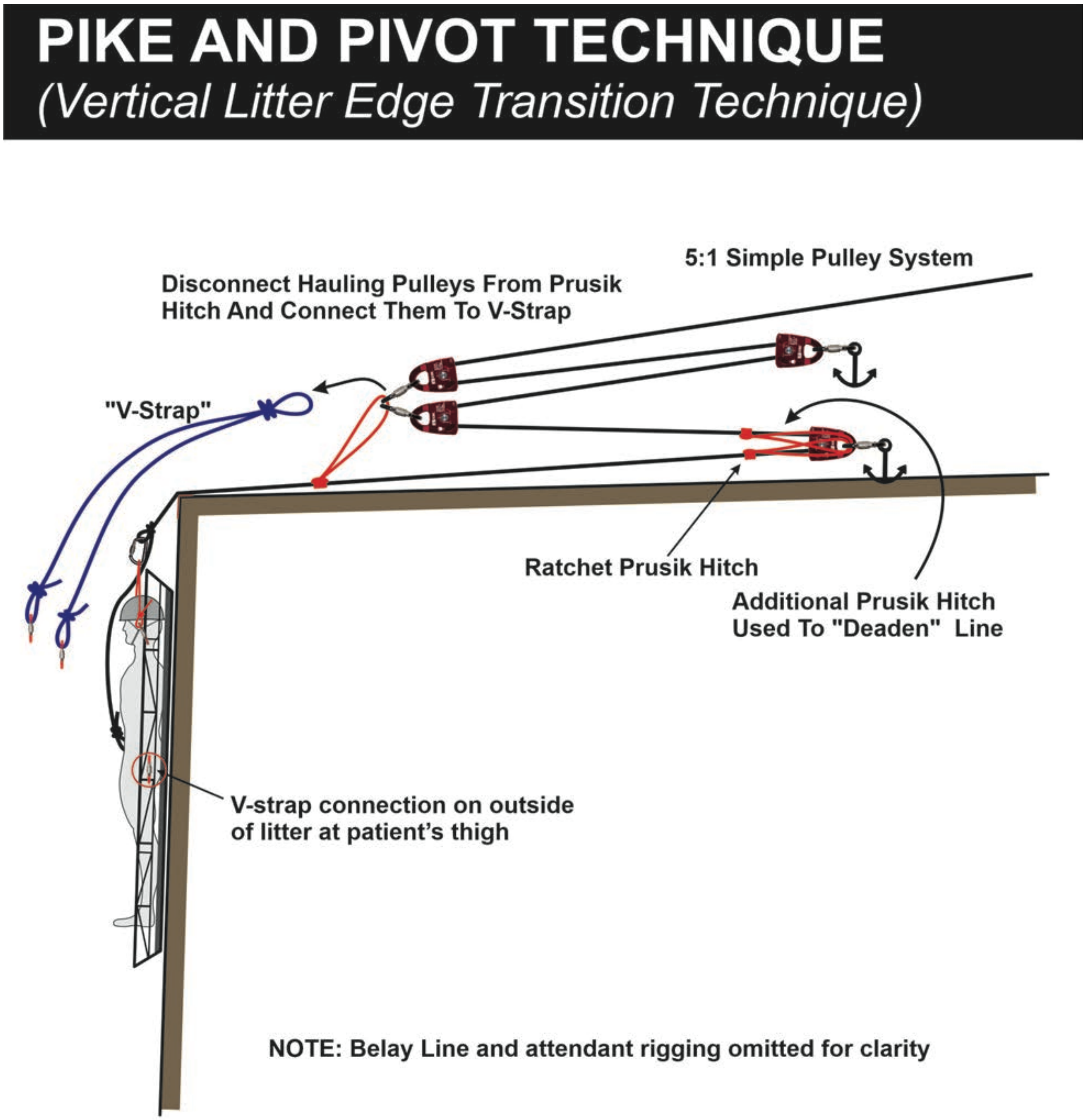


Figure 14.4-2 Pike and Pivot Technique. Image by K. Philips.

15. PICK OFFS

15.1 OVERVIEW

Pick-off technique is used to quickly rescue subjects stuck in high angle terrain. This technique is appropriate when the subject is uninjured or has minor injuries that do not necessitate the use of a litter. As few as two attendants can affect a pickoff and it can typically be done using the gear on an attendant's harness. If the subject will need to be raised to the top, this is no longer a pickoff, and a lower/raise system should be used from the beginning of the rescue.

An attendant in vertical terrain will utilize a chest harness and connector strap combination; however, in less than vertical terrain, the chest harness is not essential and can hurt the attendant back. As in litter work, if a chest harness is being used then the attachment point should be to the connector strap. The end of one of the long-tail bowlines goes through both harness masterpoints and chest harness. If no chest harness is being used, then all attachment points will go onto the seat harness.

When evaluating the location of your edge transition and fall line down the cliff, select a descent path which will not generate rockfall onto the subject. Ideally the attendant will be slightly offset to the side of the subject. The attendant must remember to bring a pick-off harness and helmet for the stranded subject, unless they are already wearing one.

APPROACHING THE STRANDED SUBJECT

Before the attendant is within reach of the subject, talk to the subject and make sure they comprehend the following:

- Do not attempt to grab onto the attendant, ropes, gear, etc.
- The attendant will attach all gear to the subject — they are not to attach, touch, or alter any gear without being directed to do so by the attendant.

Once the subject states that they comprehend and will follow instructions, the attendant continues down to an appropriate location, calls for a stop, and secures the subject.

This chapter will present two pickoff techniques: the BC (better control) pickoff and the rappel pickoff.

15.2 PICK-OFF SYSTEMS

BC PICK-OFF

The BC (better control) pick-off is described here with some adaptations from the method originally developed by Arnör Larson. The benefit of this method is that all movement is controlled by mainline operators up top, freeing up the attendant to focus on the subject. The downside is that it requires more personnel than the rappel pickoff.

Two lowering stations are rigged and the load ends of the two rescue lines are joined together with interlocking long-tailed bowlines. The attendant uses an adjustable attachment point (Purcell Prusik, Jigger, Petzl Connect Adjust, etc.) which is attached at the interlocking junction. One of the long tails is attached to the attendant.

A second adjustable attachment point ("lanyard") and the other long tail are retained by the attendant to connect to the subject's harness. It is helpful to have an adjustable lanyard that is longer than the attendants. A jigger-type device makes moving the subject from their line onto the rescue system easy and straight-forward. If an adjustable lanyard is being used, have it pre-rigged to the correct length before beginning the operation. A standard length sling will also work as a lanyard, but doesn't have the flexibility of being adjusted once weighted.

For the operation, the attendant is lowered down towards the subject and calls for a stop above them. Depending on how the subject is going to be transferred onto the rescue system will determine where the attendant will stop in relation to the subject (see Section 15.3). Once the subject states that they comprehend and will follow instructions, the attendant should proceed by attaching the subject to the rescue system. This may include putting a rescue harness onto the subject. The lanyard and long-tail can both be clipped to the belay loop on the subject's harness. Don't spend the time trying to tie the long tail through the harness masterpoint.

At this point, the subject needs to be transferred from their rope or their stance onto the rescue system. If they are not attached to their own rope, the attendant can have the subject lean back and weight the system. This will look different with every scenario. Once the subject is on the rescue system, the attendant can call for down slow and be lowered to the ground with the subject. If the subject is weighting their own line, they will need to be raised slightly to transfer their weight off their rope and onto the rescue system. The various methods to do this are described in Section 15.3.

RAPPEL PICK-OFF

The main benefit of the rappel pick-off is it only requires two rescuers to execute. A downside is that the attendant must manage both descent down the fixed rappel line and also the subject. In the two person rescue team, one rescuer serves as attendant, and the other is the belayer. The attendant and patient rigging connects at a master attachment point (MAP). The MAP can be a small rigging plate, a God Ring, or simply a sewn sling folded over many times into a "donut" (for size, not strength, considerations — see figure 15.2-2). Onto this MAP, the descent control device (DCD), the belay line with a long tail, the attendant's adjustable attachment lanyard, and the subject's adjustable attachment lanyard will be connected. The long-tail will be attached to the subject's harness.

The attendant will additionally rig a "third hand" or auto-stop hitch below the DCD on the rappel line. This will be connected to the attendant harness. The attendant should be able to adjust their length from the MAP with their attachment. Make sure the auto-stop hitch cannot be defeated by the DCD. Operationally, the subject is attached to the rescue system the same as in the BC pick-off method, with a lanyard and long-tail clipped to the belay loop on their harness. Once the subject is attached to the rescue system, transfer tension if needed, then continue safely to the ground.

15.3 TRANSFERRING TENSION

If the subject is suspended on another rope, transferring tension from their line onto the rescue system will require a short raise. How far you will need to raise the subject is dependent on multiple factors: rope type (static or dynamic), how much stretch is in the rope, and the length of rope in service. Generally, a five foot raise is sufficient to slacken the subject's line enough to untie it but the team needs to be prepared for a longer raise. If there is reason to believe the raise will need to be more than 5 ft, a full changeover may be a better option than ganging on a short raise system.

Tension transferring is the same for both pick-off methods and can be accomplished either at the anchor station or with the attendant. This should be decided on before the attendant goes over the edge and will be dependent on the mission profile. When the attendant reaches the subject, they should keep the rescue lines weighted. This will help minimize the amount of raising required to transfer tension.

Once the weight is off the subject's rope and onto the rescue system, the connection to the subject's line should be terminated. Ideally the attendant would untie/unclip the subject from their line. Cutting should be avoided as you are introducing a sharp edge near tensioned lines.

Cutting the subject's line during a pick-off without first removing the tension in their rope could result in a shock load to the rescue system. Transferring tension by raising is a more controlled means of safely transferring the load.

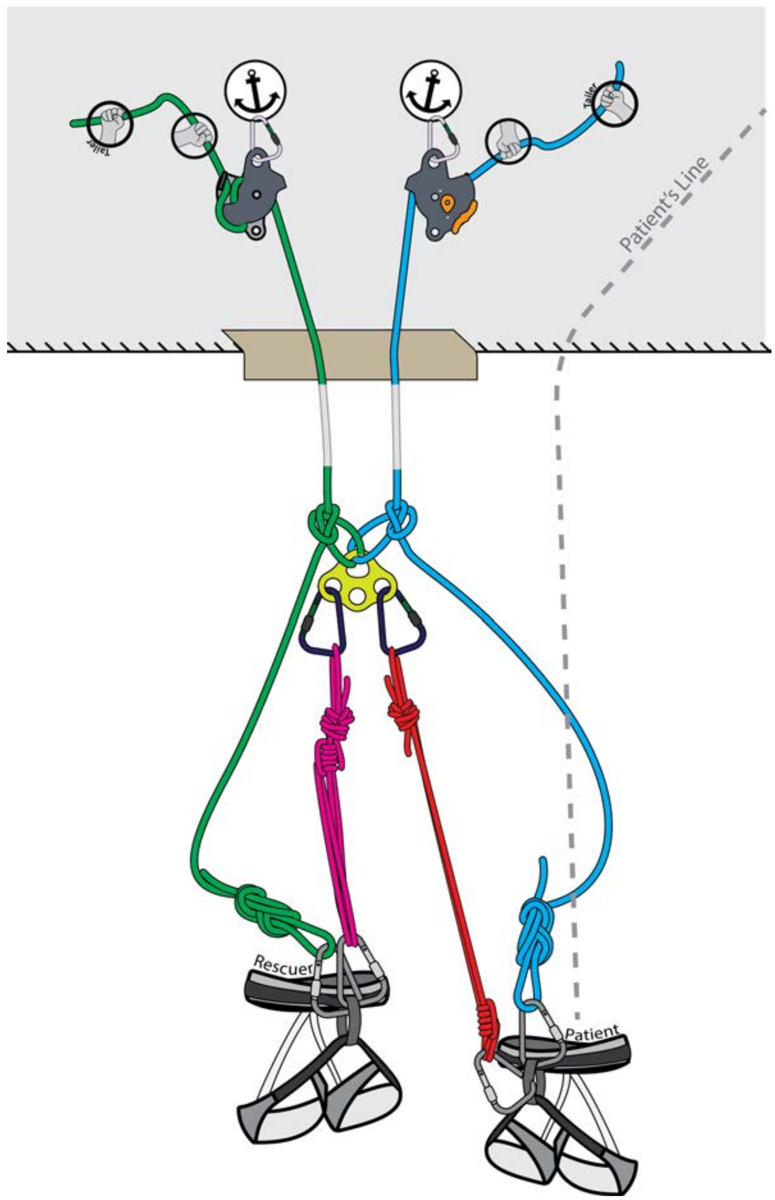


Figure 15.2-1 BC Pickoff

ANCHOR STATION RAISE

If the raise is going to take place at the anchor station the attendant can come even with the subject before calling for a stop and attaching the subject to the rescue system. The rescuers can start building their raise system as soon as the attendant gives the command to stop and rig for raise.

Since it is not a full changeover to a raise, the quickest method is to gang-on a raising system using either a jigger or the end of one of the main lines. This only needs to be done on one line.

Once the attendant has called for a stop on the raise and the tension has been completely transferred, all slack needs to be pulled out of the lines. If the rappelling pickoff method was used, the attendant needs to make sure any slack is pulled through their descent control device as tight as they can manage. The attendant and subject will still primarily be weighting the line the raise occurs on until they begin moving towards the ground. When the lowering begins, it will need to start with the lowering station at the top until the attendant has weighted their rappel line and tension evens out. Then they can start to rappel with the subject. For the BC pickoff method, the rescue team on top will need to take up any slack on their second line before continuing towards the ground.

ATTENDANT RAISE

If the attendant is planning on transferring tension, they will need to have a way to raise the subject. To do this, they will also need to pre-plan how much they will have to raise the subject. The MAP will need to be stopped this planned distance above the subject. The simplest and easiest way for the attendant to raise the subject is by attaching the subject to the rescue system with a jigger. Make sure when you attach the jigger to the subject you have the jigger extended enough that you can raise the subject sufficiently to un-tension their rope. Have the

Figure 15.2-2 Master Attachment Point (MAP) made with a sling folded over. Be sure to clip through all the correct strands of the sling.

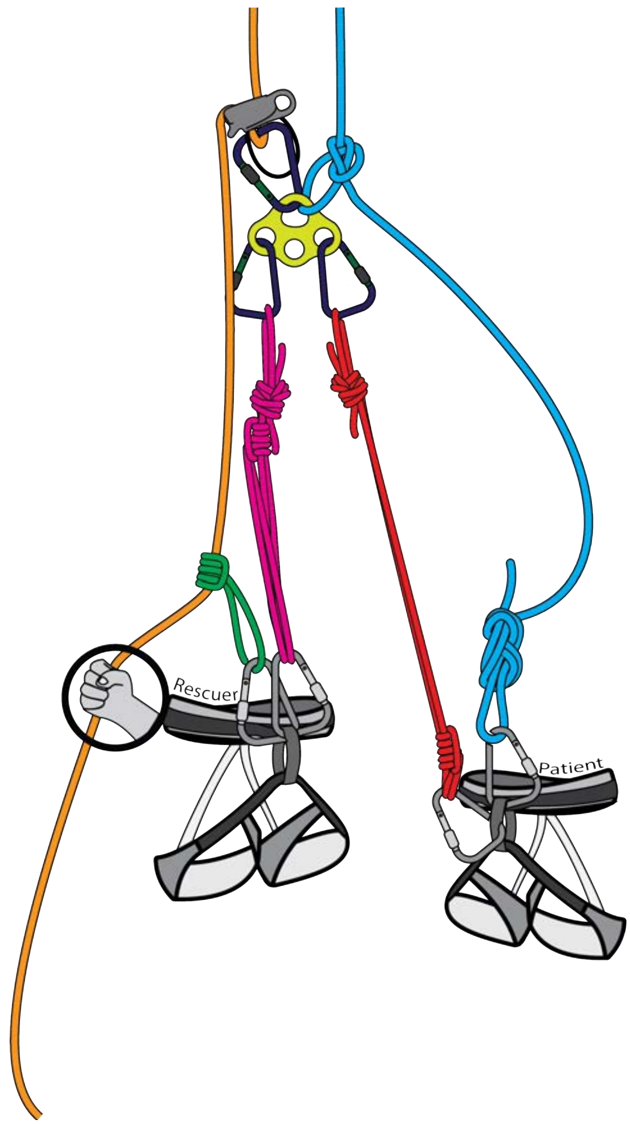


Figure 15.2-3 Rappel Pick-Off

jigger preset at the extended length before beginning the operation. With the MAP stopped above the subject, the attendant can talk the subject through safely attaching the jigger to their harness OR lower out on their attachment point to the subject and attach the jigger themselves. Once the jigger and long-tail are attached to the subject, the attendant raises the subject on the jigger until the subject's rope is slack and can be removed.

Other methods such as a 2:1 pickoff strap or counter-balancing can be used if the attendant is trained and comfortable in them.

15.4 SUBJECT POSITIONING

The subject can be placed into three different positions, depending on injuries and situation.

- **Side-by-Side:** A stable uninjured subject can be transported laterally adjacent to the attendant. They will be "walking" down the wall with the attendant. It may be helpful to slightly offset the subject, preferably lower than the attendant, to help with footing.
- **Piggy-back:** The attendant can piggyback the subject with the lanyard running over one shoulder, keeping the subject away from the rock face. The lanyard should be long enough on the subject and short enough on the attendant to keep the lanyard from digging into the attendant shoulder. When possible, the subject should be about the same size or smaller than the attendant. If the subject is larger than the attendant, one of the other methods is preferable.
- **Cradled:** The attendant cradle-carries the suspended subject in front of them. The subject is in a seated position above the attendant's legs. With this method, it is advantageous to attach the patient as close as possible to the MAP. Their legs can be extended and slung out in front of them (parallel to the wall) with a sling attached to the MAP. This is beneficial for subjects with minor leg injuries.

16. GUIDING LINE TECHNIQUE

A guiding line is employed to keep the patient and attendant away from loose, dangerous terrain by “floating” them a few feet away in the air during a lower. (Figure 16.1-1) The guiding line is more than a "tag line," which would simply attach beneath a litter to permit personnel below to provide tension and deflect the litter's path. The guiding line provides an independent aerial ropeway for a guiding pulley, which is linked to the litter, to move along as a managed directional.

Figure 16.1-1 - Guiding line technique.

An important consideration for the site selection and construction of a guiding line is that it requires concave terrain. If the terrain and slope are not concave, or do not have sufficient vertical portions near the top there is the risk of over tensioning the rope system in an effort to keep the litter off the ground. It is recommended there be adequate space or concavity in the terrain to permit approximately 15 degrees of available sag to account for rope stretch. If employing a guiding line from the top of a cliff, then this should not be a problem with the high point on the cliff.

This technique can be viewed as a "low-tech highline,” but it is important to understand that it is not designed to suspend loads a significant distance in the air. During transport with a guiding line the load should not be more than one meter away from the rock face or slope. This results in a very short pendulum into rock face if the guiding line fails. If there exists a significant potential for injury due to the height that the load is suspended, then another technique should be employed. When operating a guiding line in sloping terrain where the rescuer can safely walk, such as a talus field, then it is only necessary to have the patient and litter suspended on the guiding line. The attendant can walk next to it.

The mainlines are joined to a litter harness with interlocking long-tailed bowlines. The adjustment of the guiding line is performed with a simple 3:1 or 5:1 pulley system to tension or un-tension as necessary. A compound pulley system would require an increased number of resets to move rope in or out and therefore be less practical and less efficient. The addition of a ground level directional pulley in front of the pulley system will permit horizontal control of the pulley system.

GUIDING LINE COMMUNICATIONS	
Main Line:	• "Main Line Up" • "Main Line Down"
Guiding Line:	• **"Guiding Line— Take In"** *(Tension Guiding Line)* • **"Guiding Line— Let Out"** *(Slacken Guiding Line)*

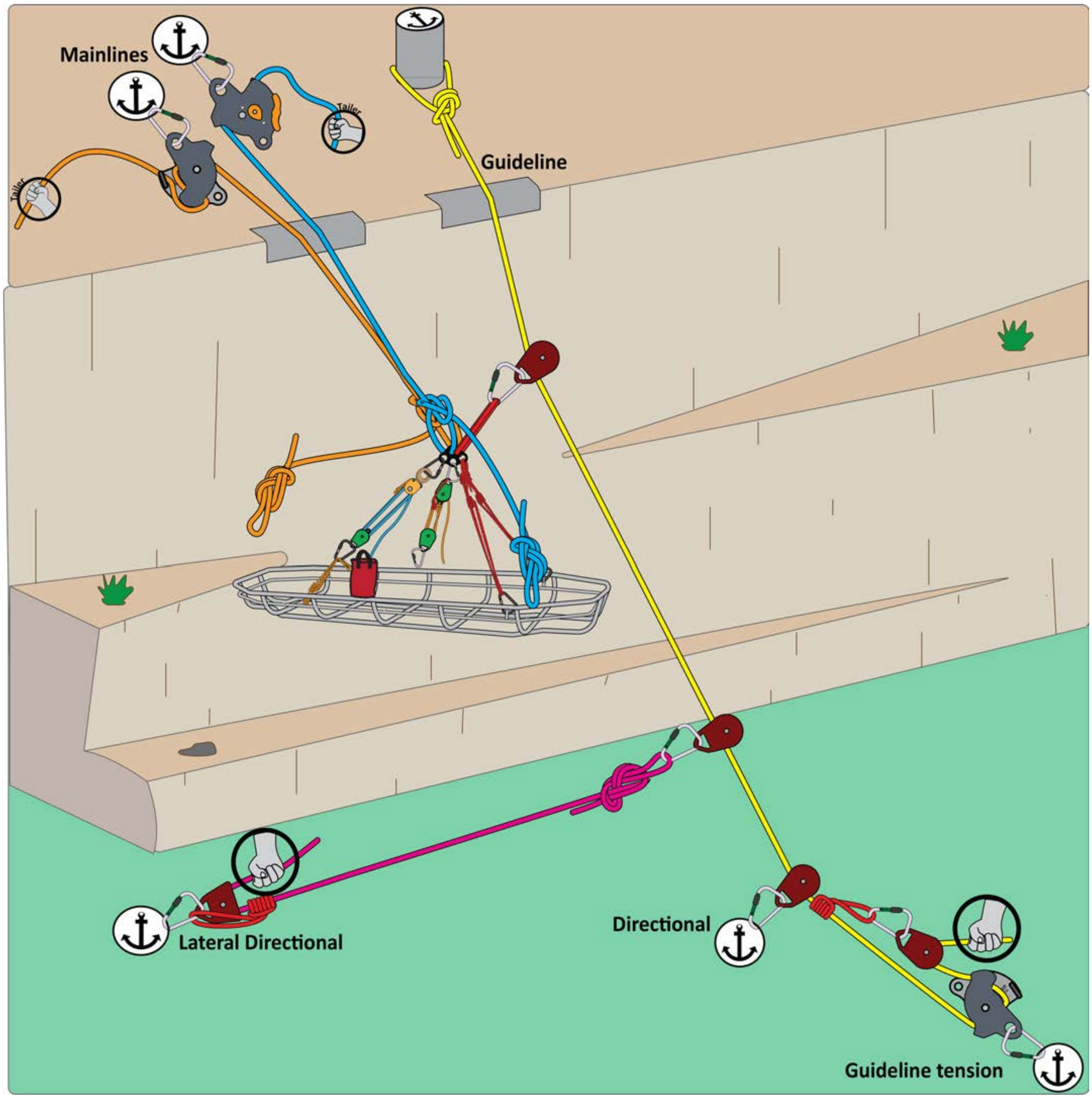


Figure 16.1-2 - Guiding Line Diagram

17. STEEP ANGLE RESCUE

17.1 OVERVIEW

The environment in which rescue work takes place dictates the equipment and tactics used by a team on any given mission. The terrain, as it pertains to slope angle, is generally divided into three steepness grades which require differing tactics due to the force vector (a magnitude and direction) of gravity acting either on the slope or the rope system (Figure 17.1-1). These rigging decisions are a balance of slope angle, rescue load, surface structure (loose, slick, grippy, etc.) and fall consequence.

Low Angle rescue takes place on slopes less than 35 degrees and much of the rescue load is supported by the ground through the feet of the litter attendants. The catastrophic fall potential is low and, with the proper footwear, most of the work can be done by the attendants. In a low angle setting where rescuers have secure footing and the rope system is the belay or assists with movement, single rope technique is oftentimes a reasonable approach with limited risk and consequence. If at any time using a single rope system a rope failure would result in serious injury or death, then a two rope system is warranted.

Steep Angle rescue occurs in terrain between 35-60 degrees and the rescue load is more evenly distributed between the rope system and the rescuers feet on the ground. In this system the rescue load is dependent on the rope system for both upward travel and descent control. The fall consequences can range from moderate to catastrophic. A two-rope system is necessary in this terrain, due to the risk of inertial runaway. This chapter is dedicated to the nuanced techniques and tactics required in steep angle rescue.

Steep Angle rescue techniques are employed in a wide variety of environments and terrain, such as on roadside embankments, steep alpine rock slabs and ridges, scree or talus slopes, or near waterways where the slope and/or fall consequences warrant a technical approach utilizing a two-rope system. Typically, in this setting there are 3-4 rescuers carrying/attending the litter and two ropes attached at the head of the litter, each of which are managed by separate devices attached to independent anchor systems.

High Angle rescue is defined by terrain steeper than 60 degrees and is covered in detail throughout the rest of this manual.

17.2 HOW MANY RESCUERS?

In steep angle rescue with slopes between 35-60 degrees, a portion of the rescue load (value R in Figure 17.1-1) is supported through the ground which warrants more attendants to support the litter and patient than during high angle operations. The applied load to the system can be high with these additional attendants. However, because they are standing on their feet and not suspended in free space, only a portion of their mass is supported by the rope system.

Angle (°)	200 kg (2 people)	280 kg (3 people)	360 kg (4 people)	440 kg (5 people)	520 kg (6 people)
0°	0	0	0	0	0
5°	0.17	0.24	0.31	0.37	0.44
10°	0.34	0.48	0.61	0.75	0.88
15°	0.51	0.71	0.92	1.12	1.33
20°	0.67	0.94	1.21	1.47	1.74
25°	0.83	1.16	1.49	1.83	2.16
30°	0.98	1.37	1.76	2.16	2.55
35°	1.12	1.57	2.02	2.46	2.91
40°	1.26	1.76	2.27	2.77	3.28
45°	1.39	1.95	2.5	3.06	3.61
50°	1.5	2.1	2.7	3.3	3.9
55°	1.61	2.25	2.9	3.54	4.19
60°	1.7	2.38	3.06	3.74	4.42
65°	1.78	2.49	3.2	3.92	4.63
70°	1.84	2.58	3.31	4.05	4.78
75°	1.89	2.65	3.4	4.16	4.91
80°	1.93	2.7	3.47	4.25	5.02
85°	1.95	2.73	3.51	4.29	5.07
90°	1.96	2.74	3.53	4.31	5.1

Figure 17.2-1 Table of Applied Forces Angle vs Load Note: The shaded regions do not represent a "No Go" zone but indicate where a 10:1 SSSF is exceeded due to the applied load and the use of standard rescue equipment. Table courtesy of Rigging for Rescue, How Steep is Too Steep?, 2003.

Static forces on a system with multiple rescuers and a patient can be higher than the 2 kN applied by a free-hanging standard rescue load (i.e., 200 kg). For example, a patient in a litter with three rescuers attending is estimated at 360 kg. This load on a 45-degree slope results in 2.5 kN applied force to the rope system (Figure 17.2-1). However, the relative worst-case scenario described in the BCDTM (See Chapter 4) does not exist in steep angle terrain due to the lack of a true edge. "We need to keep in mind that the relative worst case event in this environment will not produce the same potential peak force as a 1 m

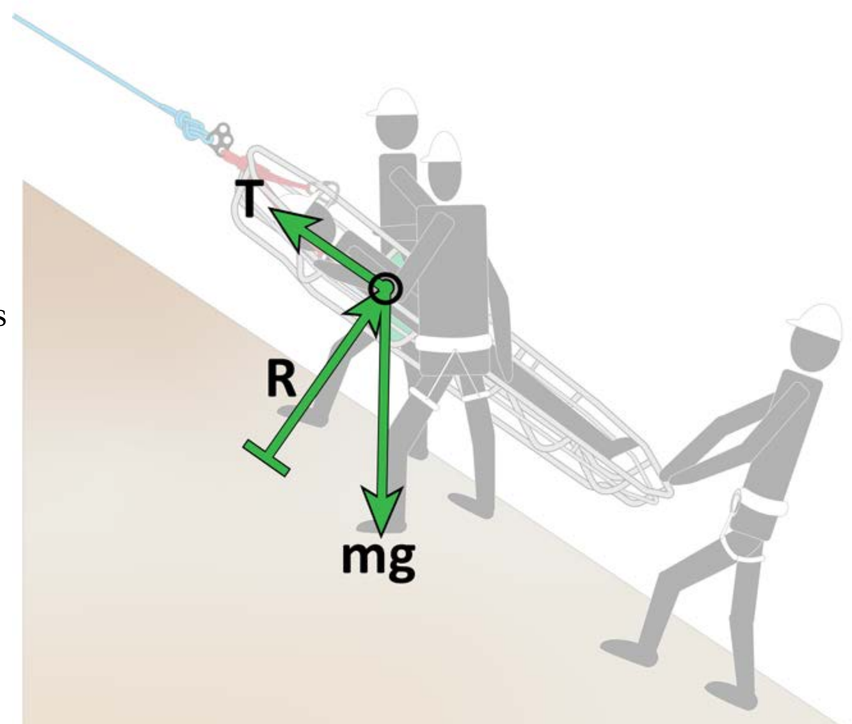


Figure 17.1-1 Free body diagram

drop on 3 m of rope with a 200 kg mass (this can produce a peak force of about 8-12 kN, whereas on a steep slope, the peak force is generally 2-2.5x the static force, or about 5-6+ kN, or about half of what an edge transition force can produce)"[33]. If a 10:1 SSSF standard was used in steep angle rescue the system would need to be built to 25 kN or greater. The result would be a significantly overbuilt (and inefficient) system, knowing there is no possibility of the BCDTM worse-case scenario in steep angle rescue terrain. Instead, a force limiting system application can be used by building the system to 20 kN and using a vetted decent control system to minimize peak forces.

17.3 LITTER RIGGING CONSIDERATIONS WITH MULTIPLE ATTENDANTS

Rescuers should be tied into the system for steep angle terrain because of the potential fall consequences and the difficulty in travel. This should include two tie-in points, ideally involving a personal adjustable lanyard to the bridal focal point and a friction hitch onto one of the long tails of the rescue ropes (Figure 17.3-1). If the adjustable lanyard goes under the top rail of the litter the attendants will have more leverage to lift the load with their harnesses when they lean back. Rescuers positioned opposite each other on the litter should be paired by similar mass.

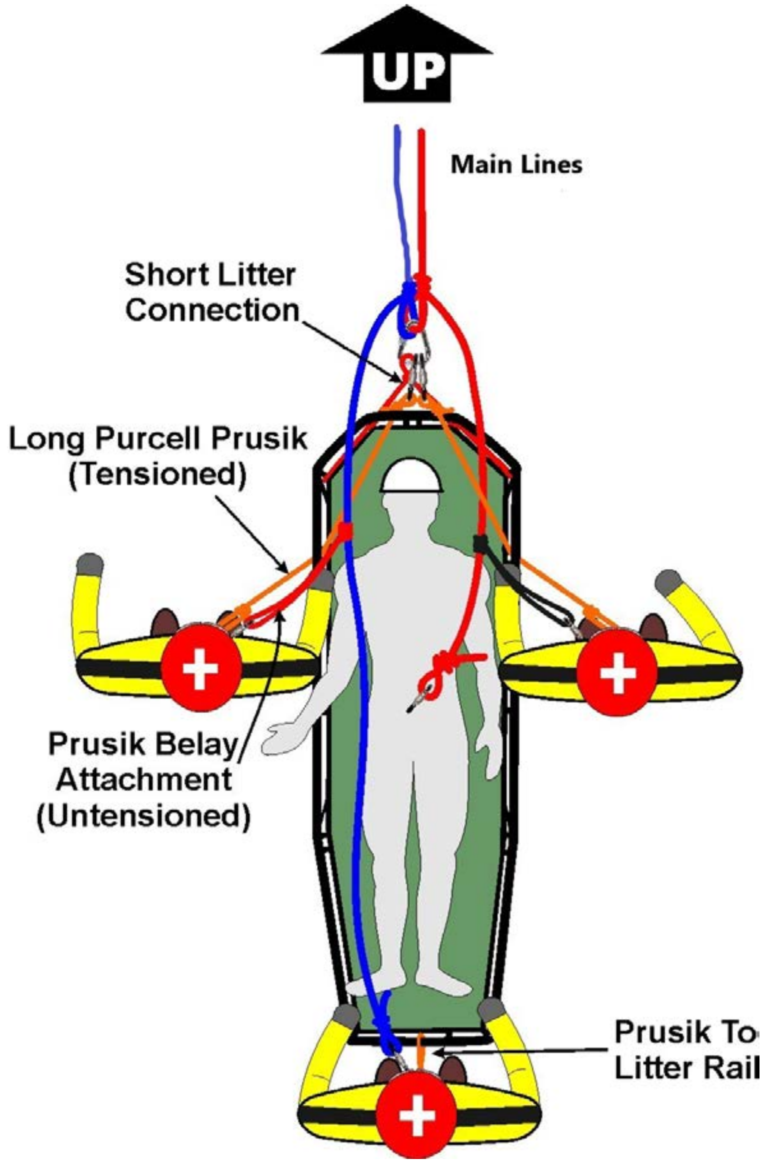


Figure 17.3-1 Steep Angle Litter Rigging

The rescuers on the side of the litter should lean back to place more of the litter load on their harness and the rope system. A short/compact litter attachment or bridle (Figure 17.3-2) will maximize the work the rope system is doing and be more efficient for the attendants to lean against, allowing the litter to clear high points in the terrain.

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In summary, during steep angle rescue (35-60 degrees) it is warranted to vary the number of attendants depending on the slope angle, patient mass, and footing. In less steep terrain consider four or five attendants to carry the litter. When the terrain is steeper reduce to three attendants for more efficient movement and lower applied force on the system.

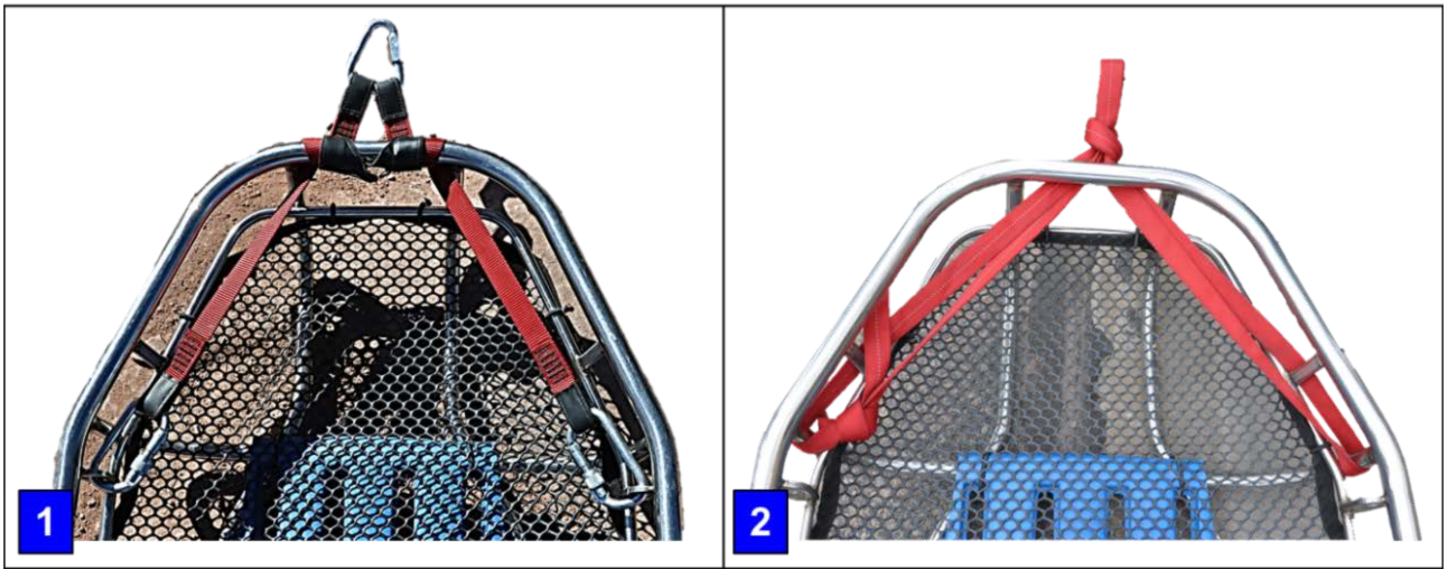

Figure 17.3-2 Compact Litter Bridle for Steep Angle 1. Fixed leg litter harness. 2. Improvised tied webbing.

18. INDEX

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