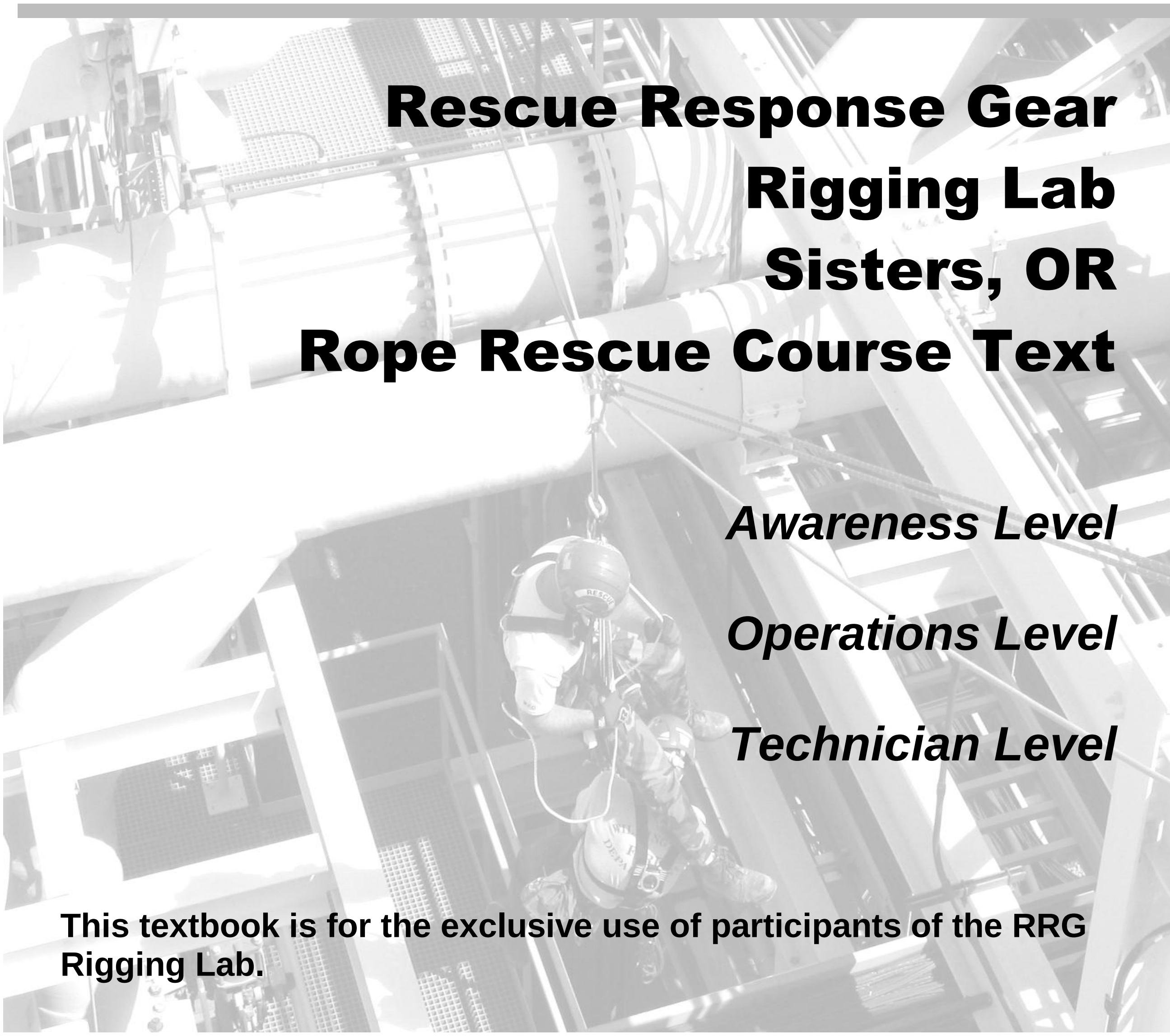

Rescue Response Gear
Rigging Lab
Sisters, OR
Rope Rescue Course Text

Awareness Level

Operations Level

Technician Level

This textbook is for the exclusive use of participants of the RRG Rigging Lab.

Pat Rhodes

Rope Rescue Course Text

Disclaimer:
This book is intended for the exclusive use of participants of the RRG Rigging Lab.

Rope rescue is inherently dangerous, even if the techniques, procedures and illustrations in this book are diligently followed, serious injury and/or death may result. This book makes no claim to be all-inclusive on the subject of rope rescue. There is no substitute for quality training under the guidance of a qualified instructor.

Insofar as the author of this book has no control over the level of expertise of the reader of this material, or the manner this information is used, the author assumes no responsibility for the reader's use of this book.

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RescueRig Rope Rescue Course Text

Contents

Section 1, Awareness Level

Chapter 1: Commitment to Excellence

We will often attempt to maintain a 10:1 safety margin with our rope equipment. In a static state, we will analyze our weakest link in the system and try not to exceed 1/10 of its maximum rating. This is known as the Static System Safety Factor, or SSSF. Although this equipment/system rating will be discussed in depth throughout this book, right now I'm using the SSSF as an analogy to the quality of your team's training.

Put a number, or hypothetical rating between 0 and 100 on the skill level needed to safely and efficiently complete a worse case scenario technical rope rescue that is potentially possible in your area of response. Remember, this is only a self-comparison scale. We will give an example and choose the number 50 to represent a difficult confined space/high angle industrial litter extrication that involves multiple changes in the fall line and challenging focused-floating anchor considerations.

Now rate your training. In our example, a rating of 50 or a 1:1 Training Program Safety Factor (TPSF) would mean that our team's training is scarcely good enough to get the job done. It probably would not be very pretty, it could take an inordinate amount of time, and yes, there would be an excessively large "pucker factor" by almost everyone involved, but hopefully, they would eventually get the job done, and with a bit of luck everyone would go home safely to their families that night.

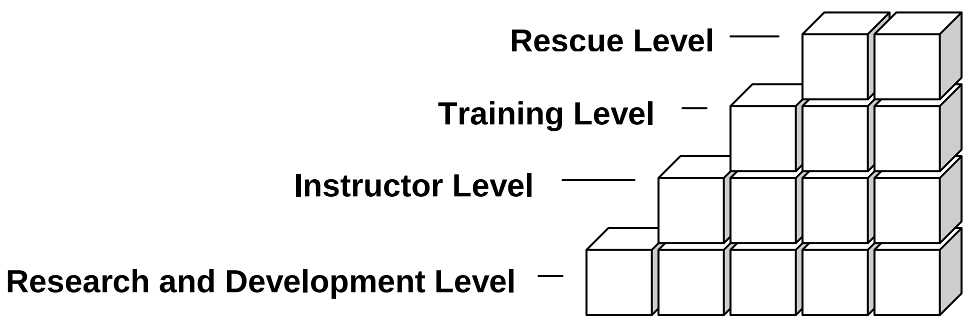
What if our example TPSF rating was only 25 or a ½ : 1? Our training would be deemed extremely insufficient. We might experience a catastrophic system failure resulting in a major injury or death of the victim and/or the rescuer. Instead of you going home at night to your family, your family would get a sorrowful visit from a department representative and our station flags would be flying at half-mast.

On the flip side of the coin, what TPSF rating would you anticipate in order to maintain a high degree of skill, efficiency, confidence, and safety? A level of training that would entitle us to be so good that the media would marvel at our expertise, speed, and safety with style! 100? Using our equipment safety margin analogy, this is only a 2:1…still pretty weak. If our rope systems are expected to meet a 10:1 safety margin, why shouldn't our training do so as well? Isn't the manner we use our equipment as important, even more important, than the equipment itself? If our TPSF was a 10:1 we would assign a 500 to our training program.

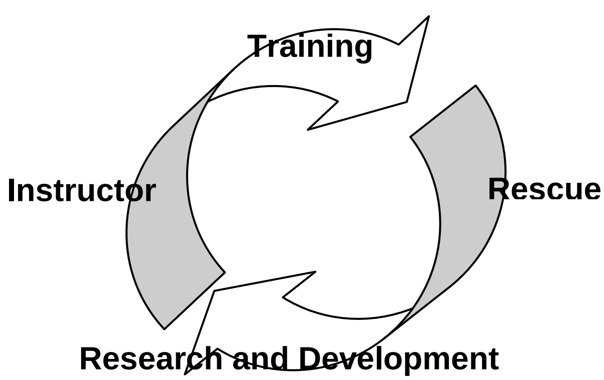
Again, this is highly theoretical. The message we are trying to convey is, when the real technical rescue call comes in, the stress level is at a peak level, conditions are most likely at their worse, and chaos rules. To avoid being sucked into this turmoil vacuum, the technical rescue technician must train at a substantially higher skill level than those that are required to perform the actual rescue. The technician who routinely trains to a higher level will easily and by design, default to the most straightforward, efficient, and safest technique possible when the real deal happens.

Technical rescue training must be based on potential, and not on call frequency. It is a total commitment by the individual technician as well as the entire agency. *Technical rescue training is dangerous; the only thing more dangerous is not training.*

Building Blocks of Technical Rescue



Note the simple graph analogy above. Each block of the graph represents those things that are instrumental in performing a successful technical rescue. These blocks include personnel, equipment, training, and leadership. Each level is supported by the larger and more substantial level immediately below. The Rescue Level is supported by training level blocks that are more extensive and demanding higher skills. The Training Level is supported by the instructor level. Conversely, these instructors must be held to a higher level of understanding and performance than what is required at the training level. The Instructor Level is reliant on continual input and support from the Research and Development Level. Each level drives and influences the other levels. Indeed, this profession is never stagnant, it is always changing. Our calling should be to ride this wave of evolution and become the best technical rescuers possible.



The Bottom Line – Don't Get Anyone Hurt!

What is the bottom line? As professional technical rescuers, what is our biggest concern? What fears do we have when dealing with these and other technical rescue disciplines?

The National Fire Protection Association (NFPA), without question, is the most recognized Firefighter/rescuer general consensus standard in the United States. Although NFPA does not have any authority to enforce or regulate the standards it has published, they do offer substantial guidance for today's technical rescue technician. To quote NFPA 1670;

> *"While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards".*
>
> *"Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances".*

"The exercise of reasonable care in any given circumstances" is a key legal phrase in coping with our bottom line – "DON'T GET ANYONE HURT"

Don't get anyone hurt is our number one goal. A distant second place concern is, if someone does get hurt, did we do everything possible to avoid the injury? Finally, if an injury does occur, what will be the interpretation of our legal system?

How do we prevent death and injury in a profession that demands us to put our lives on the line? To borrow a training philosophy from the Army, keep it simple, applicable, and repetitive.

Safety is everything – when it comes down to it, it's the only thing. Lack of safety during a rescue becomes an emergency in its own right. It is the responsibility of each team member to be on guard against non-safe situations. Catastrophic failures can always be traced back to the accumulative effect of several "lesser" mess-ups, over-sights, or in many cases, simple lack of knowledge, and training. Safety is a mindset all rescuers must possess.

Some of these lesser mess-ups may have their beginnings in the purchase of sub-par equipment. Seek sound judgment and quality training in the use of the best equipment available, no matter what the labeling is.

Most equipment standards have little legal impact on the type of equipment we use in technical rescue – more important – *did we use the equipment in accordance to the manufactures recommendations.*

This is not the case with NFPA 1670 Standard on Operations and Training for Technical Rescue Incidents, and NFPA 1006 Standard for Rescue Technician Professional Qualifications. Both of these standards have been adopted by the American National Standards Institute (ANSI), this could become a very good legal source of ammunition for a personal injury attorney.

NFPA 1670 applies to technical rescue procedures of the department, while NFPA 1006 is geared more to the skill level of the individual technician. Because these standards were adopted by ANSI, they both point their legal fingers at the Authority Having Jurisdiction (AHJ), or in other words, the local fire department and its leadership.

Most fire departments are very good at providing continued education and documenting the training of its members at the technician level, but if the AHJ is to be consistent with 1670, technical rescue awareness level and operational level training and documentation must be addressed as well.

Although these standards imply that the AHJ has a tremendous amount of flexibility over what level of rescue it chooses to be involved in, there is one other notable area of liability. NFPA and ANSI require the AHJ to conduct periodic hazard analysis and risk assessment surveys in the organization's response area for the purpose of identifying the types of technical rescues that are most likely to occur. These hazard analysis and risks assessments shall by reviewed and updated on a scheduled basis and as operational or organizational changes occur.

Suggested Training Schedule for Continuing Education

Note: Technical rescue disciplines are vast, and this schedule makes no attempt to cover all areas of technical rescue. The following training schedule addresses only vertical rescue, confined space rescue, and swiftwater rescue.

Vertical Rescue

Actual training depends on the desired skill level. This is what I would recommend as a minimum yearly, continuing education standard:

Awareness-level - *Low Angle Evacuation (Less than 40°)*.

- Rig and operate a tag line on a litter.
- Perform a caterpillar pass.
- Perform proper patient packaging.

4 hour class, 2 times per year. 8 Hours Total

Operational-level - *Steep* (40° to 65°*) To High Angle (more than* 65°*) Evacuation*s.

- Awareness skills. 8 hours
- Personal skills (climbing, rappelling, self-rescue) Two 4hr. classes, 8hrs. total.
- Rigging and operating a basic rescue system (bombproof anchors, mainline, belay line). Two 4hr. classes, 8hrs. total.
- Rig for lower, rig for raise, and convert from a lower to a raise and a raise to a lower. Two 4hr. classes, 8hrs. total.
- Perform simple mid-face pick-offs (team base, and rescuer base, with a non-changing fall line). Four 4hr. classes, 16hrs, total.

48 hours per year.

Technician-level - *High Angle With Multiple Changes In The Fall Line.*

- Awareness skills plus, Operational skills. 48 hours total.
- Rigging multi-point anchors. Two 4hr. classes, 8hrs. total.
- Understanding fall factors, understanding ideal and practical mechanical advantage. Two 4hr. classes, 8hrs. total.
- Rig high directionals. Two 4hr. classes, 8hrs. total.
- Rig multiple offsets. Two 4hr. classes, 8hrs. total.

80 hours per year.

Advanced Technician-level - *Highline Operations, and/or Structural Tower Rescue.*

- Operational skills, plus, basic and intermediate skills. 80hrs. total.
- Review highline operations, and structural tower rescue.

Two 8 hour classroom sessions per year, 16hrs. total.

Advanced anchor rigging.
Two 4hr. classes, 8hrs. total.

- Rig 1, 2, and 4 rope highlines, rig English and Norwegian reeve highlines, horizontal and steep highlines (all one time per year).

8hrs. each, total 32hrs.

- 2 simulated structural tower rescues per year.

8hrs. total.

152 total hours per year.

Chapter 2, *Managing a Technical Rescue*

Elements of a Vertical Emergency

An element of a vertical emergency is a factor, condition, or influence that can be redirected, and treated by the rescue team. A strong rescue team will draw from their “skill” toolbox and deal with these elements in a safe and expedient manner.

How does a rescue element effect the choices of the rescue team? What elements determine the manpower needed, or the amount of equipment needed at the scene? Too often rescuers make these decisions with little training and experience.

Most fire departments have the expertise to perform a low angle carryout. Most technical rescue personnel can rappel, do some basic climbing, and complete a rescue involving a non-changing fall line. But ask yourself, does your team have the skills to perform a mid-face pick-off that includes a fall line with multiple obstacles, or extricate an injured worker off the top of an electrical transmission tower.

Some elements are minor some are major. It is the accumulative effect of these elements that change the course of action. A successful rescue is the direct result of a team’s ability to recognize these elements and deal with them with confidence.

Elements of a technical rescue emergency can be divided into three major phases, Primary Assessment, Recon, and Rescue.

Primary Assessment Phase

Command – Establishment of a strong command structure starts with the first unit on the scene. This includes a complete on the scene report to the dispatch center confirming that you are on the scene, what obvious conditions, exist, and what your initial plan of action will be.

Witnesses – If possible, secure witnesses. Witnesses can offer valuable information on the location and condition of the victim. For additional reference, keep reliable witnesses close at hand to the command post.

Time of Day – Time of day may be a major element for command to consider. How much daylight is left verses the predicted length of time needed for the rescue may determine such things, as lighting needs, and the possible use of additional resources, such as helicopters.

Weather Conditions – Weather conditions, or impending changes in the weather can alter the direction of a rescue operation. Weather conditions can be the primary safety concern for rescue personnel.

Vertical Type – Although all vertical rescues have similarities, different types, whether they be mountain/wilderness, urban/industrial or structural towers, can be vastly different in the resources, and skill levels needed.

Terrain – Although a true evaluation of the terrain comes from the recon sector, most of the time command can get a good idea of what kind of terrain the rescue may involve.

Resources – Based on information at hand, call for the appropriate resources early. When in doubt call for more than you need, you can always turn units around. It is always better to have too much than not enough.

Skill Level – As Command, you must have the personnel with the level of skill to bring the rescue to a safe and successful conclusion.

Vertical rescue is not unlike other rescue incidents, such as auto accidents, or structural collapse, it isn't uncommon for treating a trapped patient, even for extended periods of time, while waiting for more advanced extrication specialists to arrive.

It is much wiser to wait for members with more advanced rigging skills to arrive, than attempt a difficult vertical extrication with members that may not be up to the task. This does not preclude treating the victim in place.

Recon Phase

Recon – Command must establish a recon sector as soon as possible. Recon are usually the first rescuers over the edge, or up the mountain. These members become the initial "eyes and ears" of command.

Victim Profile – As soon as possible command needs to know what the victim profile is. Is the operation going to be a rescue or a recovery? This element alone will dictate the speed and urgency of the operation.

Other considerations that may play into developing a victim profile is the victim's location, the victim's vertical stability, and effects of weather exposure.

Recon sector should include paramedic members with the medical equipment available to deliver advanced life support if needed.
The recon sector should be capable of evaluating any other victim/patient needs that will promote timely treatment, and extrication, including patient packaging, and litter configuration.

Terrain – Command will get its most accurate report of what kind of terrain he/she is dealing with from the recon sector.

Angle and Length of Ascent/Descent – Based initially of recon's report, the angle and length of the ascent and/or descent will determine the type of rescue profile (low, steep, or high angle), and the skill level of the personnel (non-technical, basic, intermediate, or advanced technical skills).

Horizontal and Vertical Distance From The Fall Line – Does the fall line change? Does the fall line include obstacles? Does the main line and belay line package need to be altered to affect the rescue? If so, the rescue team will need to be versed in performing any number of "offset" evolutions.

Helicopters – Is the terrain conducive to helicopter use? Helicopters are some of the most versatile and useful tools known to the rescue world, yet the use of a helicopter in a vertical rescue can be one of the most dangerous. Members must be highly trained, and command must do a complete risk assessment before a helicopter is chosen to extricate the victim.

Rescue Phase

Team Base Location, Top or Bottom – As simple as this sounds, the decision on where to start the operation is one of the most important. Starting at the top and working down to the victim is most often the preferred way. But in many scenarios, such as a structural tower, there is simply not enough room to work above the victim.

In the case of the "bottom" operation, a limited number of rescuers will work above the victim, setting high directional, and doing the victim packaging, while the bulk of the team is doing a support/rigging operation on the ground or below on a larger working area.

Anchor Profile, – Anchor selection, and who's building the anchor are the two biggest decisions to be made during the rescue phase.

Good *"bomb proof"* anchors are single point anchors that everyone is happy with, and there is no chance that the anchor will fail. Any well-trained basic technical rescue technician can rig this type of anchor.

Marginal *"multi-point"* anchors are anchor points, that by them self, are questionable, but when used in combination with each other make for a very strong system anchor. This type of anchor should be handled by members with strong intermediate skills and who have a full understanding in building load sharing, load distribution, back-tie, and focused anchor systems.

"Advanced anchor" construction is rare. This is developing an anchor where no apparent anchor exists. Typically this involves several advanced skills such as, back-ties, front-ties, focused, and floating anchor systems, plus the use of bolts, cams, and wedges. Team members with advanced rigging skills should only manage these types of anchors.

Edge Profile/High Directional Needs – The number one enemy of rope is sharp edges. What resources are needed to protect the rope?

A good rescue system will keep the majority of the rope off the ground. The best way to accomplish this is by using some form of a high directional.

A high directional, in addition, to edge protection will also lessen "edge trauma" to team members going over the edge.

Rescue Vertical Direction – Down or up, or any combination of, this element requires skills in setting up and operating a system brake rack, a system belay, a mechanical advantage system, and the technical skill in converting between a lowering and a haul system.

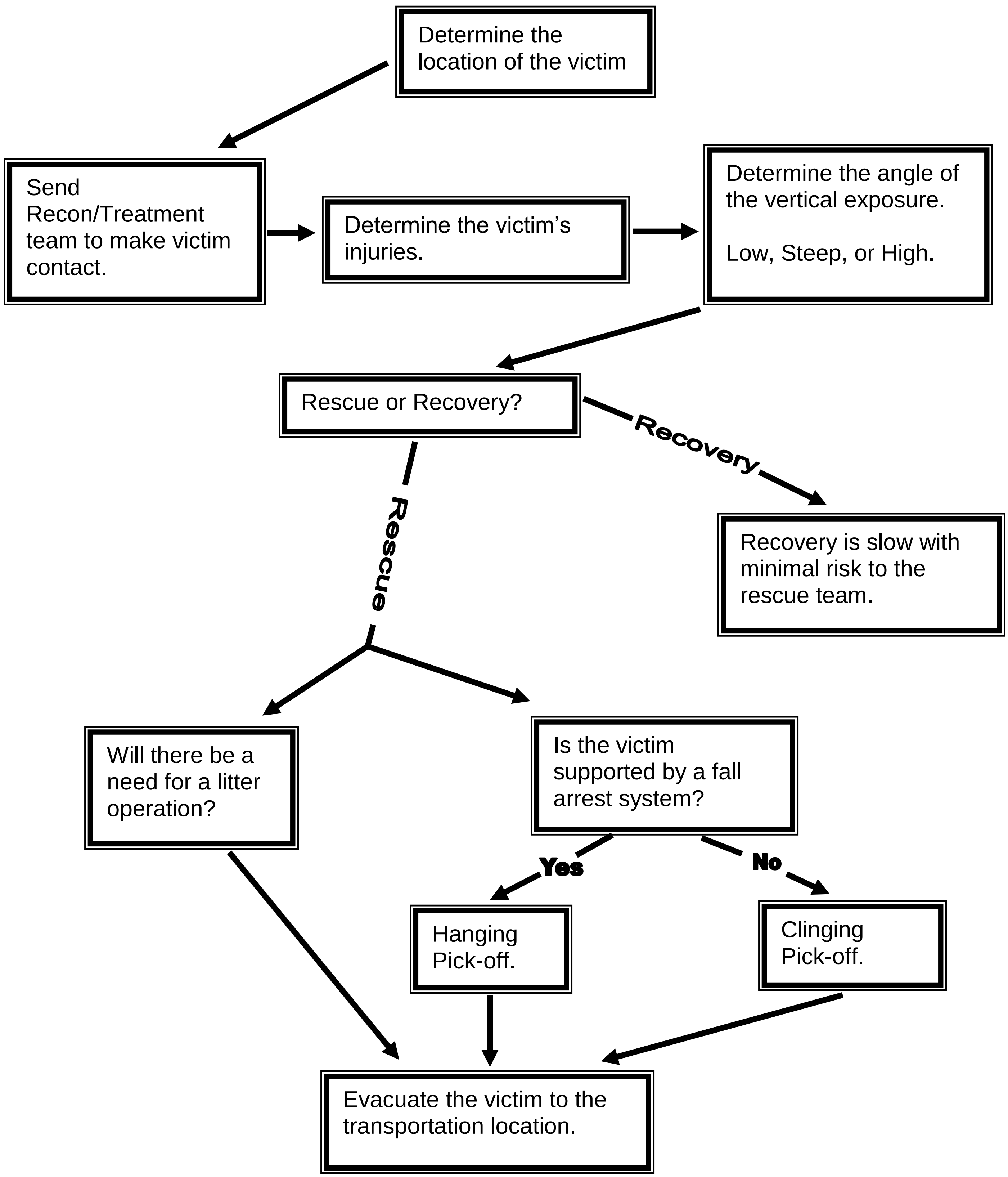
Rescue Vertical Distance – How much rope is needed? This may involve skills in combining lengths of rope in a safe and reliable manner, and the ability to pass knots through the system.

Rescue Horizontal Changes – Is there a need for *horizontal systems*, add on systems that allow the team to manipulate the main line, and sometimes the belay line in a horizontal manner.

Long Horizontal Distance – On very rare occasions a rescue team may be called upon to build and operate a highline system that facilitates a rescue over a long expanse.

This would be that one time that the terrain would not allow the use of a helicopter, and the distance was too long to use offsets. Advanced technical rescue technicians should only attempt this type of rescue.

Vertical Rescue Decision Flow Chart



Hot, Warm, and Cold Zones

Zones are established by Command for the purpose of scene management.

Hot Zone

The Hot Zone is ground zero, the location of the actual rescue. No one should be allowed inside the Hot Zone who is not directly involved with the hazard entry and victim extrication. The *Lobby* is the point of entry into the Hot Zone. Entry into the Hot Zone is strictly enforced by *Lobby Sector*.

The diameter of the Hot Zone is established by Command based on the following key factors:

1. Type of emergency – i.e. hazmat vs. tower rescue with downed lines, a hazmat emergency may require an entire building to be designated as the Hot Zone, whereas downed electrical lines may require a Hot Zone diameter of 500'.
2. Location – is it in a open field or a location more confining like electrical vaults or trenches?
3. Number of rescuers and equipment required to work within the Hot Zone.

Warm Zone

The Warm Zone is the emergency support area surrounding the Hot Zone. Typically, the Warm Zone extends 300' beyond the outside boundary of the Hot Zone, again, this is a command decision based on location and support needs.

The Warm Zone includes *Level One Staging* – staging of immediate needs resources.

Cold Zone

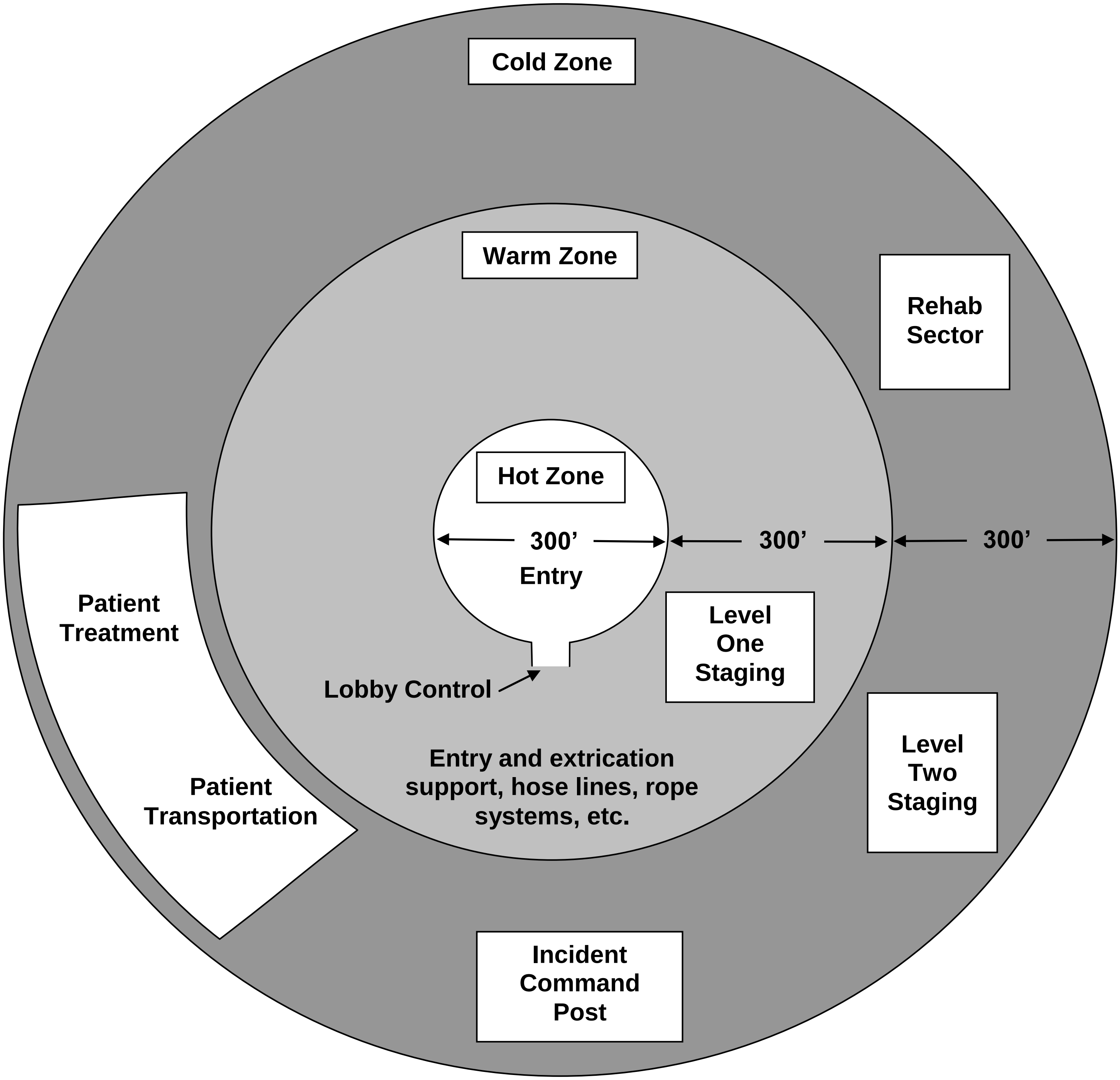
The Cold Zone is the non-emergency support area surrounding the Warm Zone. Typically, the Cold Zone extends 300' beyond the outside boundary of the Warm Zone, again, a command decision based on needs.

The Cold Zone includes *Level Two Staging* – staging of potential needs resources.

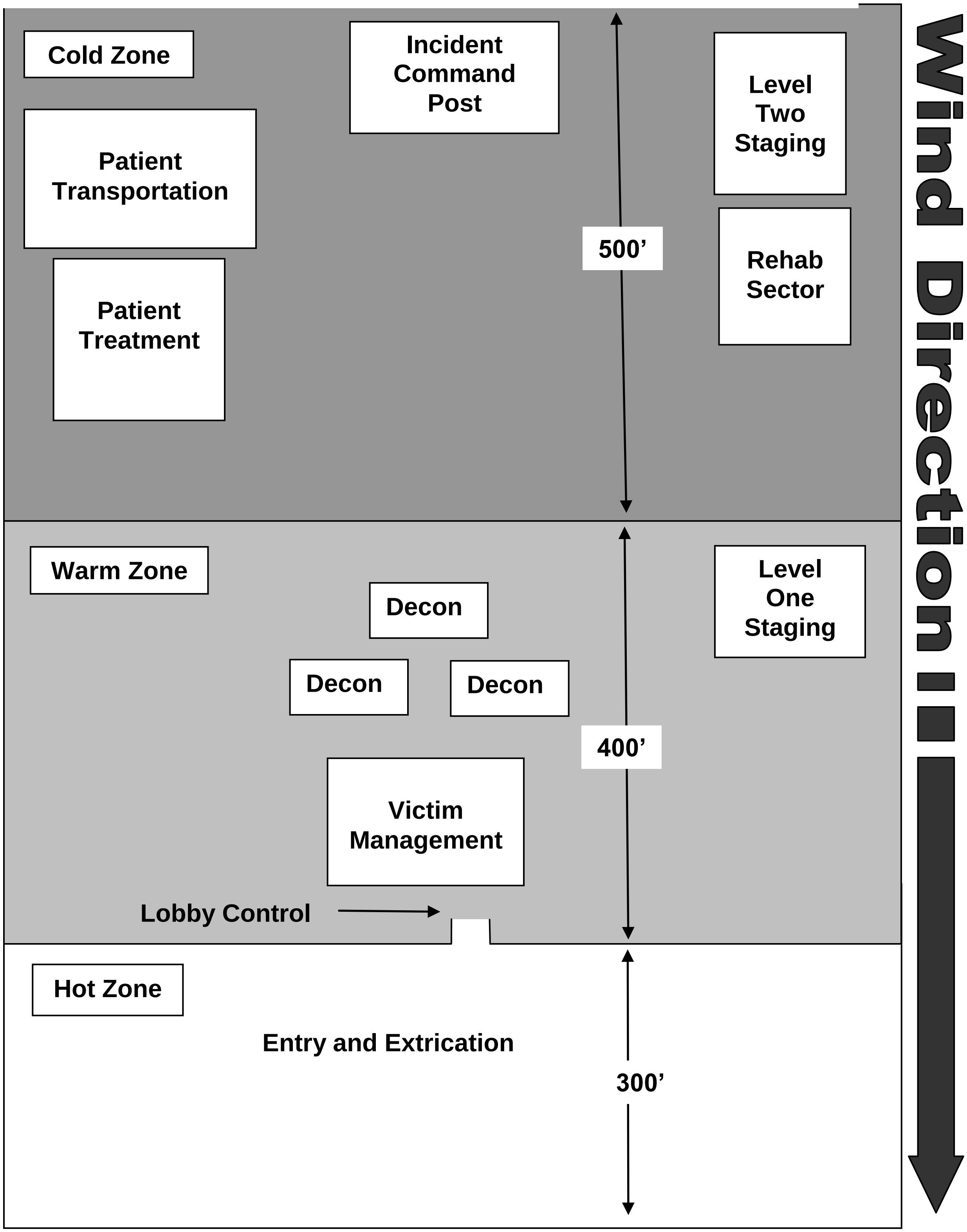
Note: All those not playing a role in the rescue operation, including bystanders, and media must be kept outside of the Cold Zone boundary.

Use Emergency Zone Tape, it works!

Command Zone Scheme (Typical)



Command Zone Scheme (Hazmat and Confined Space)



Tactical Worksheet for High Angle Emergencies

Phase 1. Size up

- ☐ Primary Assessment
  - ☐ Secure witness/RP.
  - ☐ Determine location and number of victims.
  - ☐ ID immediate hazards to the public and rescuers.
  - ☐ Rescue mode or recovery mode?
- ☐ Secondary Assessment
- ☐ Type of Structure
  - ☐ Non-technical (<40^{o})
  - ☐ Technical (>40^{o})
  - ☐ Tower
- ☐ Assess the need for additional resources.

Phase 2. Pre-rescue Operations

- ☐ Make general area safe. (Cold Zone)
- ☐ Make rescue area safe. (Warm Zone, Hot Zone if possible)
  - ☐ Establish lobby control and accountability for Hot Zone.
  - ☐ Designate a safety officer.
  - ☐ Designate a Technical Rescue Officer (TRO).
    - ☐ Equipment Management
    - ☐ Technical Safety
    - ☐ Mainline
    - ☐ Belay Line
    - ☐ Qualified Climber/Lead Climber (Tower Rescue)
    - ☐ Attendant/Rescuers
    - ☐ Edge/High Directional Personnel
    - ☐ Offsets/Highlines
    - ☐ Other Personnel
  - ☐ Develop incident action plan.
- ☐ Proper personal protective equipment for the rescuers is in use.
- ☐ Appropriate rescue and patient packaging equipment is on scene.
- ☐ Personal protective equipment for the victim in on scene.
- ☐ Pre-rescue briefing.

Phase 3. Rescue Operations

- ☐ Technical Rescue Officer (TRO) commences rescue operations.
  - ☐ Complete role call of technical rescue stations.
  - ☐ On belay!
  - ☐ Rescuer(s) into hazard zone.
  - ☐ Rescue Package out of hazard zone.
  - ☐ All stop! Rescue complete.

Phase 4. Termination

- ☐ Remove equipment.
- ☐ Personnel Accountability Report (PAR)

National Incident Management System – Overview

On February 28, 2003 President Bush released HSPH-5 which ordered the creation and implementation of a national incident management system. The National Incident Management System (NIMS) grew out of a notable lack of a unified command structure during 911 as well as Federal concern with the absence of an incident command system that was standard across the nation.

While originally ICS was the focus, NIMS soon grew into an entire emergency management organization system. NIMS is extremely similar to the California Standardized Emergency Management System (SEMS) and wildland firefighting command systems. It is the goal of NIMS to provide a consistent nationwide approach for responding to all kinds of incidents – no matter what the size, scope, cause or complexity.

Chief benefits of NIMS

It is Applicable across jurisdictions and functions.

- Used for all types of emergencies
- Encourages interoperability
- Enhances the ability of different classes of responders to work effective together

Concepts and Principals

- NIMS provides a <u>flexible</u> framework that facilitates government and private entities working together to manage domestic incidents.
- NIMS provides a set of *standardized* organizational structures, as well as requirements for processes, procedures, and systems.

NIMS is comprised of several components that work together as a system to provide a national framework for preparing for, preventing, responding to, and recovering from domestic incidents

- Command and Management
- Preparedness
- Resource Management
- Communication and Information Management
- Supporting Technologies
- Ongoing Management and Maintenance

The Incident Commander

- Fix the responsibility for Command on a certain individual through a standard identification system, depending on the arrival sequence of employees, rescuers, and supervisors.
- Ensure that a strong, direct, and visible Command will be established from the onset of the incident.

- Establish an effective incident organization defining the activities and responsibilities assigned to the incident commander and the other individuals operating within the Incident Command System.
- Provide a system to process information to support incident management, planning, and decision making.
- Provide a system for the orderly transfer of Command to subsequent arriving supervisors

Command Tactical Objectives

The incident commander is responsible for the completion of the following tactical objectives:

A. Provide for the continued safety of non-involved personnel and bystanders.
B. Provide for the safety, accountability, and welfare of rescue personnel. <u>This priority is on-going throughout the incident</u>.
C. Remove endangered occupants and treat the injured.
D. Stabilize the incident.
E. Conserve property.

The Incident Command System is used to facilitate the completion of the tactical objectives. The incident commander is the person who drives the Command system towards that end. The incident commander is responsible for building a Command structure that matches the organizational needs of the incident to achieve the completion of the tactical objectives for the incident. The functions of Command define standard activities that are performed by the incident commander to achieve the tactical objectives.

Functions of Command

The functions of Command include:

- Assume and announce Command and establish an effective operating position (Command Post).
- Rapidly evaluate the situation (size-up).
- Initiate, maintain, and control the communications process.
- Identify the overall strategy, develop an incident management plan, and assign companies and personnel consistent with plans and standard operating procedures.
- Develop an effective Incident Command organization.
- Review, evaluate, and revise (as needed) the Incident Management plan.
- Provide for the continuity, transfer, and termination of Command.

The incident commander is responsible for all of these functions. As Command is transferred, so is the responsibility for these functions. The first five (5) functions must be addressed immediately from the initial assumption of Command.

Establishing Command

The first rescuer to arrive at the scene of a major event requiring the rescue, victim treatment, and scene stabilization shall assume Command of the incident*. The initial incident commander shall remain in Command until Command is transferred to a supervisor, higher qualified member/rescuer, or the incident is stabilized and Command is terminated.

When possible the first arriving rescuer initiates the Command process by giving an initial radio report.

The **Radio Report** should include:

A. Identification of who is on the scene and talking.
B. A brief description of the incident situation, (i.e. building size, occupancy, type of hazard, type of accident, etc.)
C. Obvious conditions (flooding, hazmat spill, multiple patients, etc.).
D. Brief description of action taken.
E. Any obvious safety concerns.
F. Assumption and identification of Command.
G. Assume & Announce accountability location.

Incident Management

Size-up

Size-up is a rapid overview of the obvious, what is observed by everyone, and what is said by witnesses.

C.A.N. report (Conditions, Actions, and Needs)

This is an ongoing communication tool between rescue personnel and Command, the focus is on simple, direct communication.

Level 1 Staging

Level 1 staging is the immediate gathering location of first arriving rescue personnel, typically in close proximity to command, (typically, close enough for voice communication)

Level 2 Staging

Level 2 staging is a location designated by command where continued arriving resources gather and await further assignment. Level 2 staging is typically positioned well outside the field of action, yet close enough to advance forward to the scene within a couple of minutes. This allows for a systematic pooling of equipment, rescue and support personnel without overwhelming the scene with congestion.

Sectors or Groups

Sectors are subdivisions of larger command events that require a manageable span of control by Command.

Sectors are named by Command, typically using their location and/or function. i.e. North Sector, West Sector, Sector 2 (2nd floor), Rescue Sector, Hazmat Sector, or Treatment Sector, etc.

Each sector will have a Sector Officer who is responsible for communicating with Command (C.A.N. report) and supervising the actions within that sector.

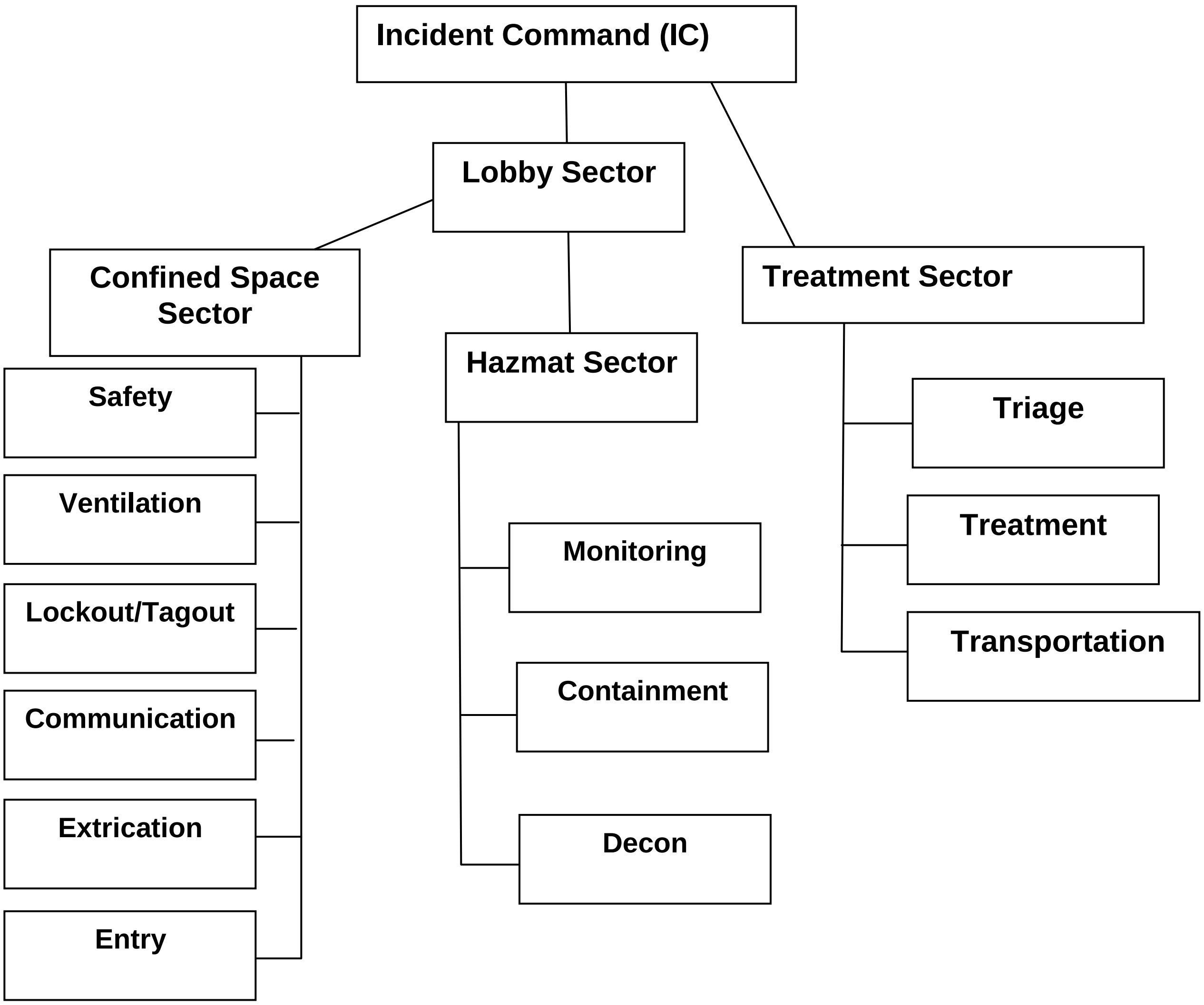
Sections and Branches

Sections and Branches are subdivisions designed for extremely large command events that require a manageable span of control by Command.

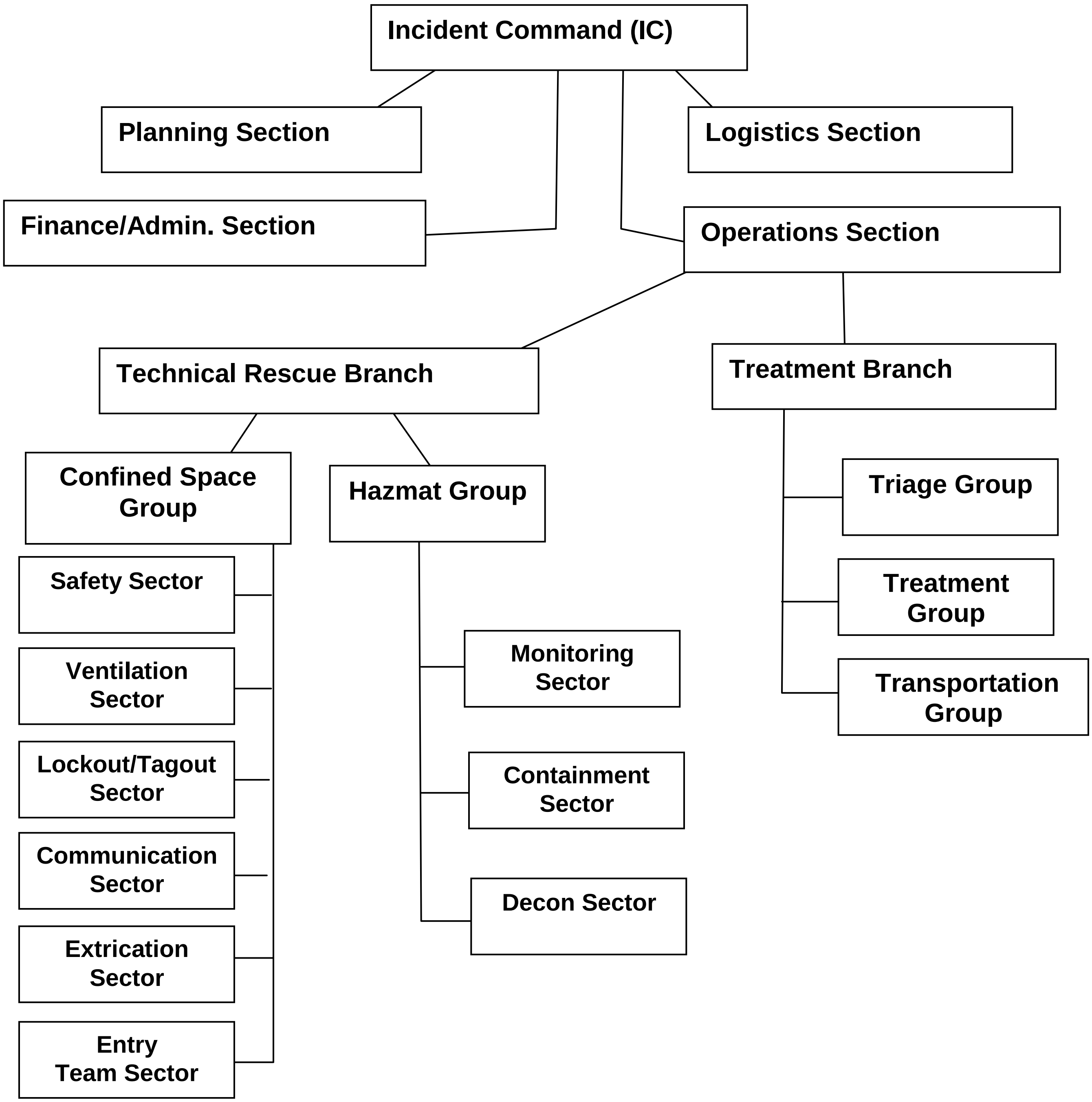
Typical Order of Command Divisions

IC → *Sections* → *Branches* → *Divisions/Groups/Sectors*

Incident Command Structure (Typical)



FEMA/Homeland Security NIMS Command Structure (Major Event)



Definitions

- **Accessory Cord –** Any low-stretch cordage [rope] made from nylon, Spectra, or Kevlar fibers and used for any number of purposes. Generally, any cord smaller than 9mm is considered an accessory cord.

- **Active Protection –** Rock climbing protection (camming devices) which have moving parts as part of the camming mechanism. Spring-loaded camming devices are considered “active”.

- **Air Monitoring –** Those actions needed to insure atmospheric safety during a confined space emergency through the use of specialized monitoring equipment. Air monitoring is the single most important diagnostic tool used in making a confined space emergency atmospherically safe. Ventilation is the prescribed treatment. Air monitoring must continue during the full extent of the rescue and must work in harmony with the ventilation sector. The areas of primary concern are:
    1. The opening of the space.
    2. The source of air being supplied to the space.
    3. The air being drafted from the space.
    4. The interior of the space (personal monitors on the entry team).

- **Anchor –** Any means of attaching the rope to an object. It may be a natural anchor such as a tree or rock formation, or an artificial anchor provided by the rescuer, such as a bolt or rock protection.

- **Anchor Types:**

    1. *Single Point” Anchors:*

       Anchors that originate from one location, such as a pole, tree, bolt, etc. A single point anchor may be bombproof or may be a marginal component of an anchor system.

    2. *Tensioned Anchors:*

       Anchors working in harmony by virtue of a back-tie system system.

- **Hard Ascender –** Hardware camming devices which grip the rope in one direction.

- **Belay System –** Protection against a fall by handling a secondary unloaded rope (belay rope) in such a manner that is may be taken in or let out yet can be secured to hold this load in case of failure of the working line or rappel line.

- **Bolt –** Artificial, reliable means of anchoring in rock requiring the drilling of holes and the placement of bolts.

- **Brake Rack –** A friction device used for rappelling or the safe control of lowering systems. Typically, the brake rack employs multiple friction bars held in place by a steel frame. The friction bars are capable of collapsing or loosening around the rope, therefore providing the needed friction for the safe control of the descent.

- **Carabiners –** Hardware used for the purpose of connecting any two points of a given rope system. Carabiners typically employ a self-closing, gate as apposed to other connecting hardware that employ manually operated screws that close the opening, see screw-links and tri-links.

- **Change of Direction Pulley –** A change of direction is a pulley on the anchor that directs the last leg of rope to the haul team, notated (cd).

- **Compound Mechanical Advantage Pulley System –** Any pulley system that is made up of two or more simple pulley systems. Example; a compound 6:1 could be a 3:1 pulling on the end of a 2:1, or a 2:1 pulling on a 3:1. The simple components are multiplied to give the compound mechanical advantage.

- **Cordelettes –** Typically, a small rope, typically 8 mm or 9 mm, and approximately 10 meters long, used for rigging. Example; small pulley systems, whipping and frapping, etc.

- **Critical Point Test –** A test rescue teams use to determine the inherent safety within a rope rescue system. In order to pass the Critical Point Test, a system must have no point or single piece of equipment which, were it to fail, would cause catastrophic failure of the entire system.

- **Directional Pulley –** A directional is a pulley or pulleys between the pulley system and the load to be raised, notated (d) or (1:1)

- **Dynamic System Safety Factors (DSSF) –** In a dynamic state, (movement and maximum system stress, with a suspended load) the ratio between the load and the weakest link in a system using the rated breaking strength of each piece of equipment in the system and a theoretical prediction of those factors that will add maximum stress to the system. For instance, any part of a given system will only hold 6000 lbs. and the work being placed on the system is 1000 lbs, including approximately 20' of rope drag at or over the edge, will in effect double the weight of the load on a raising system. The Safety Factor would then be approximately only a 3:1. A 7: 1 Dynamic System Safety Factor is a realistic goal when a belay rope is present.

- **Ganged Mechanical Advantage Pulley System –** When a separate rope used for a MA system is attached by a haul grab to a second main rope for the purpose of lifting or lowering a load.

- **Hardware –** Those components of a rope system that are made of metal.

- **Haul Field –** The haul field is the available distance a hauler or haulers can run out or the space that they have to stand and pull.

- **High Directional –** A means of suspending a loaded rope at least 2 meters above the edge so that edge trauma is reduced. There are structural, natural and artificial high directionals.

- **Horizontal Systems –** Any adjunct rope system that is employed for the purpose of changing the original direction of the mainline and belay line systems.

- **Loaded Changeover –** Those actions needed to convert the mainline from a lowering system to a raising system while the load is suspended and under tension.

- **Litter –** A device used to contain a patient and maintain stability during the extrication process.

- **Lockout/Tagout –** Those actions needed to bring all potential hazards, typically electrical, mechanical, and engulfment, to a neutral state prior to the beginning of any rescue.

- **Mainline –** Also known as the Working Line, it is the main rope system used to do the lowering and raising of the rescue package.

- **Mechanical Advantage –** The increase of the input of power for the purpose of moving objects, typically during rope rescues, this would most often include the use of pulley systems.

- **Multipoint Anchor System –** Any combination of point anchors that are employed to make one reliable anchor. The following are the two major divisions of multipoint anchor systems:

    1. *Self Distributing: (Also known as Self-equalizing)*
    A multipoint system rigged to where the force of the load is distributed between all the point anchors. Due to friction and many other unseen factors, this distribution is not as equal as most would assumed.

    2. *Fixed Multi-point: (Also known as "Load Sharing")*
    A multipoint anchor system which is distributing during the construction of this anchor and is than fixed into place, typically by virtue of an overhand loop.

- **Passive Protection –** Rock climbing protection which has no moving parts (as opposed to active protection, which does). Examples are stoppers, hexcentrics, and tri-cams.

- **Patient Packaging –** Patient packaging is the act of getting the patient ready to be evacuated.

- **Personal Loads –** Any load equal to a single person.

- **Piggyback –** A piggyback system is a compound MA that is made up of two or more ***identical*** simple MA's. i.e. a compound 4:1 (2:1)(2:1).

- **Pulleys –** A small grooved wheel used with a rescue rope to change the direction and point of application of a pulling force. They may be used in combinations to employ mechanical advantage especially for the purpose of a raising operation.

- **Rappelling –** The act of descending a fixed rope system in a controlled manner for the purpose of vertical transportation.

- **Ratchet –** A progress capture device employed for the sole purpose of holding the load in place during the reset phase of a raising operation.

- **Reset –** Action taken to re-extend the pulley system for another haul after it has fully collapsed during a raising operation.

- **Rescue Load –** As determined at the Forth Annual Technical Rescue Symposium, 1987, a rescue load is considered to be 200 Kg, 448 lbs. It is the weight of one victim/patient, one rescuer, and associated gear.

- **Risk/Benefit Analysis –** A command decision that determines the type of action needed based on the hazards present and the risk they pose to the team and the victim.

- **Rope –** Typically, kernmantle rope is the most common rope used for rescue operations. (Because of its floating properties polypropylene is sometimes used in swiftwater rescue.) Kernmantle rope is constructed of a load-bearing core, or "kern", of nylon fibers surrounded by a braided, protective outer sheath, or "mantle". The core is completely protected by the mantle and holds most of the load. It has a high strength to weight ratio, and maintains most of its strength when wet (approximately 85%). Kernmantle rope comes in two types; Dynamic and Static.

  Dynamic rope consists of twisted or bundles that make up the core. This twisted core provides a high stretch quality. This allows as much as 40% stretch in the rope, depending on the manufacturer. Dynamic rope is very important in rescue work solely for the purpose of belaying a lead climber.

  In contrast, static kernmantle rope stretches very little, from 2-4% under load. This type of rope is made from an outer braided sheath (mantle) which is woven over straight nylon fiber core (kern). The core supports 85% of the rope's strength.

  "Static" kernmantle rope is used for rigging rescue system because of its high strength, low stretch and handling characteristics.

- **Rope Grabs –** Any device attached to a rope for the purpose of holding or grabbing, may be software or hardware.

- **Screw-links –** Hardware connectors that employ a manually operated screw to close and open the gate.

- **Size-up –** The initial evaluation of the emergency scene by the first responder.

- **Soft Ascenders –** Any number of rope hitches which grab the rope in one or both directions.

- **Software –** Any rope system component that is either rope, webbing, or is constructed of rope or webbing.

- **Static System Safety Factor (SSSF) –** In a static state, (no movement, with a suspended load) the ratio between the load and the weakest link in a system using the rated breaking strength of each piece of equipment in the system. For instance, any part of a given system will only hold 5000 lbs. and the work being placed on the system is 1000 lbs.. The Safety Factor is then 5: 1. A 10: 1 Static System Safety Factor is a realistic goal when a belay rope is present.

- **System Loads –** See "Rescue Loads".

- **Throw –** The throw is the available distance between maximum pulley system extension and the need for a reset.

- **Tri-links –** Triangle shaped, hardware connectors that employ a manually operated screw to close and open the gate. Tri-links are particularly suited for multiple loading in multiple directions.

- **Webbing –** Widely used by rock climbers and rope rescuers, webbing is a flat nylon software that is relatively inexpensive and extremely strong. Although webbing has multiple uses, it is particularly suited for anchor rigging.

- **Working Line –** Also know as "the mainline", the working line is the main support rope for the rescue operation.

- **Working Load Limit (WLL) –** A rating that is sometimes used in conjunction with hardware, typically screw-links and tri-links.

Section 2, Operations Level
Chapter 3, Equipment

Personal Equipment

- ***Helmet with chin strap***
- ***Gloves***
- ***Light source***
- ***Eye protection***

Photos courtesy of Glenn Speight

Harnesses

The NFPA classifies harnesses into three types:

A Class I harness fastens around the waist and thighs or under buttocks, and designed only to be used for emergency escape with one-person loads.

A Class II harness fastens around the waist and thighs or under buttocks and is designed for rescue work where two-person loads may be encountered.

A Class III harness fastens around the waist and thighs or buttocks and over the shoulders; designed for rescue where two-person loads may be encountered and inverting may occur.

Class II

Class III

Photos courtesy of Glenn Speight

Software

Rope

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"Static" kernmantle rope is used for rigging rescue system because of its high strength, low stretch and handling characteristics.

Photos courtesy of Glenn Speight

Rope Strength

Accessory cord rope is generally considered to be diameters 9mm and smaller. It is also of kernmantle construction and has the same characteristics as larger rope. Load Releasing Hitches should be tied with 9mm rope, system prusiks should use 8mm and personal prusiks should be tied with 6mm or 7mm.

Mainline and belay line applications use 11mm (7/16) and 12.7mm (1/2") static rope. Other applications that use 12.7mm are; system mechanical advantages, anchor construction (back-ties and opposition back-ties), and guying for high directionals.

According to the NFPA 1983-2001 Standard, life safety rope is designed "for supporting people during rescue, fire fighting, or other emergency procedures, or during training evolutions". It must have a minimum breaking strength of 4500 lbs. for a single person load of 300 lbs. (includes rescue equipment). The rope must have a breaking strength of 9000 lbs. for a two-person, 600 lbs. (including equipment) load. The safety factor is 4500/300 lbs., or 15:1 for a one-person line; and 9000/600 lbs., or 15:1 for a two-person line.

Typically, life safety rope varies in lengths between 100 and 600 feet. Any rope longer than 600 feet becomes a true rope management challenge; only in extremely rare rescues would longer rope be needed.

Minimum breaking strength of various rope diameters of low stretch kernmantle rope fluctuates from one manufacture to another; but in general, they are as follows:

SIZE	BREAKING STRENGTH (lbs.)
Accessory Cord, 6mm	2500
8mm	3500
9mm	4500
11mm (7/16") rope	7500
12.7mm (1/2") rope	9000

General Rope Care

The single most important factor in rope care is good sound rigging skills.

We use rope on rope all the time in rigging applications, haul prusiks, ratchet prusiks, tandem prusik belays, and knots just to name a few. The one thing all these good applications have in common is that they are for the purpose of stopping or holding. The key question in dealing with nylon on nylon is; is there a sustained rapid motion or rubbing (even for a very short time) between two sections of rope and/or webbing. Tandem prusiks used for system belays typically involve very slow and controlled movement during normal operations; this is a safe, proven and excepted practice.

Something is dangerously wrong if there is unwanted motion in the rescue system. This principal can be applied to something as simple as tying a knot. Even a good knot will degrade a rope by as much as 35 %, a badly tied knot (leave alone the fact it could come untied) will add small amounts of movement to the rope, usually in the area of the most server bend. What makes cut rope fibers so dangerous are the extreme pressures we operate these systems under.

Use edge protection whenever possible to avoid abrasion. Redirect rope away from sharp objects and edges. Edge rollers, edge protectors, and discarded fire hose provide effective rope padding.

Rappelling also causes abrasion. Rappelling should be slow and deliberate. Fast rappels should be avoided. Friction causes excessive heat build-up and can damage the rope. It also demonstrates poor technique and lack of control on the part of the rappeller. "Bouncy" rappels should likewise be avoided. They cause unnecessary shock loading and may cause the rope to "saw" and abrade over an unprotected edge. A cut easily propagates completely through a tensioned rope once it is initiated.

Rope should be kept away from sulfuric acid (battery acid), other strong acids, bleach, hydrogen peroxide, ultraviolet light and excessive heat. Although nylon is not damaged by gasoline, rope should be kept free of petroleum products such as gasoline, kerosene, diesel fuel and oil.

Rope Inspection

All rope should be carefully inspected when first purchased, after each use, and after cleaning. Sliding the rope through one's hands to feel for any soft spots, bulges, thin areas, or other deformities can do this. Feel for changes in rope stiffness and changes in diameter, such as an "hourglass" effect. Rope can also be examined visually for deformities. Most kernmantle rope is colored. Internal core fibers are white and easy to spot if cord damage is suspected.

When an abnormality is found, or if the rope sustains a substantial shock load, the rope should be immediately taken out of service.

It is wise to keep a rope log, documenting all use of the rope, and any changes noted. Deciding when to retire a rope is a judgment call and depends on the length of time the rope has been in service and the type of use incurred. It is a subjective appraisal of the appearance of the rope and its overall condition.

Webbing

Vertical rescue utilizes two types of 1" webbing: *tubular* and *flat*. Tubular, nylon webbing of spiral stitch construction has no seam; it is rated at approximately 4000 lbs. Flat, 1" nylon webbing is also rated at approximately 4000. Webbing is most commonly used for anchor construction and tying emergency harnesses. Flat nylon webbing in various widths is commonly utilized in the construction of factory-made runners and harnesses. Webbing should be used, inspected, and stored just as rope.

Rope and Equipment Bags

Many styles, shapes and sizes

- **Protects rope from damage**
- **Assists in keeping rope from tangling**
- **Assists in transportation and carrying of rope and other accessory rescue equipment**

Hardware

Carabiners

In rigging for rescue, carabiners are the most commonly used hardware component. Carabiners are used to connect other hardware and software components of the rope system.

Photos courtesy of Glenn Speight

Carabiners

Many styles, sizes, shapes and strengths
Steel and aluminum
Primarily used for connections

Maillon Rapide Quick Links typically stamps the Working Load Limit (WLL) on their products. Below is the rating of a few of the more common screw-links and tri-links:

- 7mm   Oval — 5kN (WLL)
- 12mm Oval — 14kN (WLL)
- 10mm Delta — 8kN (WLL)
- 12mm Delta — 10kN (WLL)

Photos courtesy of Glenn Speight

Maillon Rapide Quick Links

- ***Many styles, sizes, shapes and strengths***
- ***Steel and aluminum***
- ***Exceptionally strong***
- ***Easy to use***
- ***Prevents side-loading***
- ***Not purchased at hardware stores***

Care of carabiners and all other rescue hardware should include:

- Avoid dropping or throwing.
- Keep clean and free of dirt.
- Do not oil.

Carabiners are rated in capacity by loading along the long axis. They have little strength when side-loaded along the short axis. Some offset carabiners, such as the modified "D" carabiner, help prevent side loading. *Make sure to always load a carabiner along it's spine (the long axis).*

It is dangerous to triple-load a carabiner, (to place a load on it in three directions), if the need arises, use a triangular screw link.

Do not use oil or grease-based lubricants on carabiners. Try using an air hose for gates that are stuck or slow to operate, if the carabiner still gives you grief, get rid of it, a small price to pay for safety.

Retire carabiners that show:

- Sharp edges or burrs.
- Cracks.
- Weak gate spring.
- Loose or bent gate rivets.
- Deformity.
- Or if it is known to have been shock loaded.

Know your equipment, especially carabiners, hand-me-down equipment should be avoided.

Descenders, and System Lowering Devices

Brake Racks

Brake racks are widely accepted by many rescue team for descending and system lowering in rescue work. Having said that, many new, high quality products are quickly making their way into the rescue community.

Brake Racks

Many styles, sizes, shapes and strengths
Steel frame with steel or aluminum bars
Care must be taken when installing rope so that inadvertent "zippering" does not occur.

Photo courtesy of Glenn Speight

Petzl I'D

- ***Used for lowering and descending***
- ***Comfortable to use***
- ***Controlled by brake hand and handle rotation***
- ***Easy to lock off***
- ***Can be rigged as an ascender***
- ***Can be used as a safety belay***
- ***NFPA G rated 5000 lbf. (22kN).***

Photo courtesy of Glenn Speight

Pulleys:

Rescue pulleys are most often used to create mechanical advantages for hauling operations. Many times, pulleys can be used to direct running rope to more favorable positions, creating a greater convenience for the rescue team.

There are several manufactured types of rescue pulleys that will accomplish various functions during the course of a rescue.

Pulleys typically come in one of two different axle types; bushings, and sealed ball bearings. Ball bearing pulleys are approximately 90% efficient verses the bushing type which is only about 75% efficient.

Pulleys

- ***Many styles, sizes, shapes and strengths***
- ***Primarily used for mechanical advantage systems and changes of direction***
- ***NFPA G rating 8000 lbf. (36kN)***
- ***NFPA P rating 5000 lbf. (22kN)***

Photos courtesy of Glenn Speight

Chapter 4, Knots, Bends, and Hitches

Throughout the evolution of rope rescue there has been much debate over which knot is right for this type or that type of application.

Although the knots represented in this book are substantial, it is not intended to be the last word on the subject. In this chapter you will find many combinations of knot craft that is incorporated in the rescue world, most of which we have found useful on several occasions. Hopefully, by reading this chapter you will learn some new knots, and possibly generate some new ways of incorporating them.

Strength of a knot is not as important as the quality and skill in which it is tied. Knots do not break in a system that is built within normal safety parameters by skilled technicians. The vast majority of system failures in the vertical realm can be attributed to human error.

What are Knots, Bends, and Hitches?

The standard definition of a knot is a rope intertwined with itself, a bend is the intertwining of two ends of rope, and a hitch is a knot that is dependent on a host object. In the true spirit of the art of knot craft, defining knots deserves a little more than “intertwined rope!”

The first thing that comes to mind when we visualize “rope intertwined with itself” is the broken body of a rock climber lying dead on top of a heap of “intertwined rope”, only because he lacked the skill in tying the appropriate knot somewhere in his system.

Or as Clifford Ashley (probably history’s greatest authority on knots) put it**,** *“A knot . . . is either exactly right or it is hopelessly wrong.”*

By its very nature, vertical rescue is dependent on rope, and the most elemental skill in using rope is tying it into a knot. There are no gray areas, no “in betweens” in tying knots, Mr. Ashley goes on to *say “Make only one change and either an entirely different knot is made or no knot at all may result.”*

This statement holds true in this business of high angle rescue, there is but only a careless visual difference between a slipped Figure Eight, and a Figure Eight on a Bight Follow Through. The Figure Eight on a Bight Follow Through is a great knot for securing a rappel harness, and under the same application, the slipped Figure Eight will drop you like a rock!

Knots, bends, and hitches are defined by their function. It is the responsibility of the rescuer to use the most appropriate knots for the job at hand.

As with all systems within a vertical rescue, safety is a team issue. At least two (2) qualified team members should inspect all knots involved in the rescue operation before anyone is allowed to move into the hazard zone.

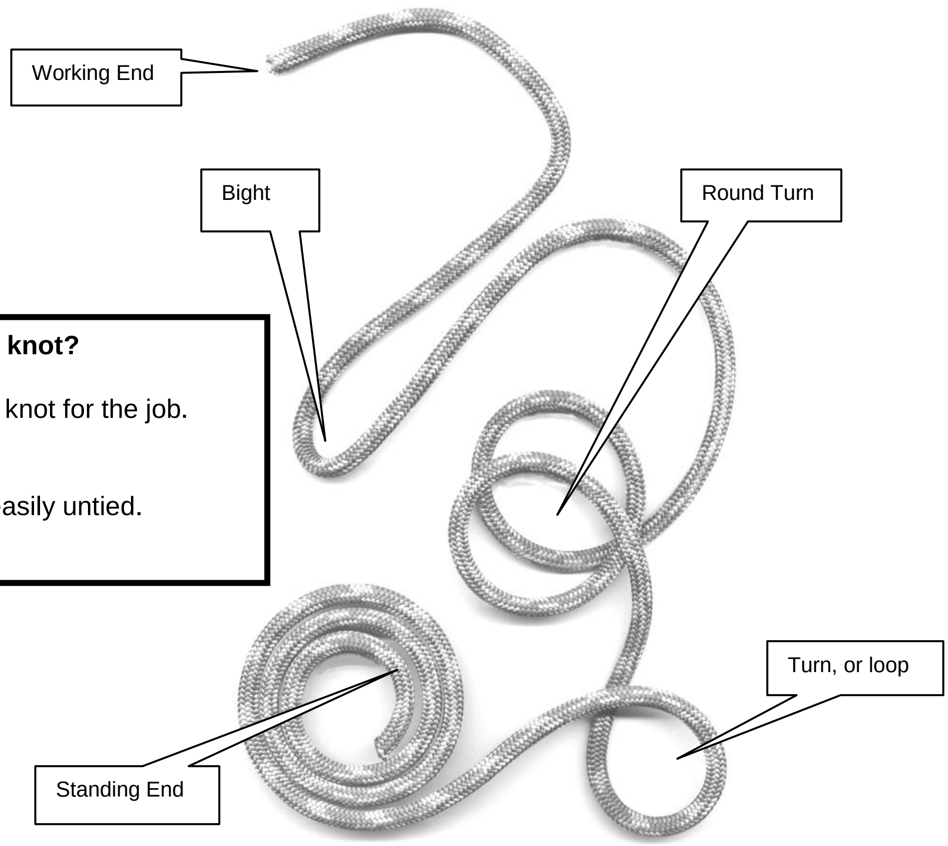
In summery, knots are the first link in the success, or failure of a vertical emergency.

Knot Families:
In this chapter on knots, you will find a slightly different presentation with the division of knots, bends, and hitches. We have found over several years of teaching knot skills, that knots, and bends, are easier to learn if they are kept within the context of their respective "families."

Example, it is very simple to follow the progression from an "overhand" to an "overhand on a bight", to a "double overhand", to a "double overhand bend".

Hitches, because they are dependent on a host object, are categorized in their own section.

Elements of a Knot

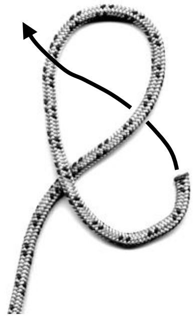


What makes a good knot?

- Most appropriate knot for the job.
- Recognizable
- Cleanly dressed.
- When required, easily untied.

The Overhand Family

Overhand



The overhand (the half hitch or single hitch is the most basic knot) is the second most elemental knot. It was probably the first knot ever tied in a vine by ancient man.

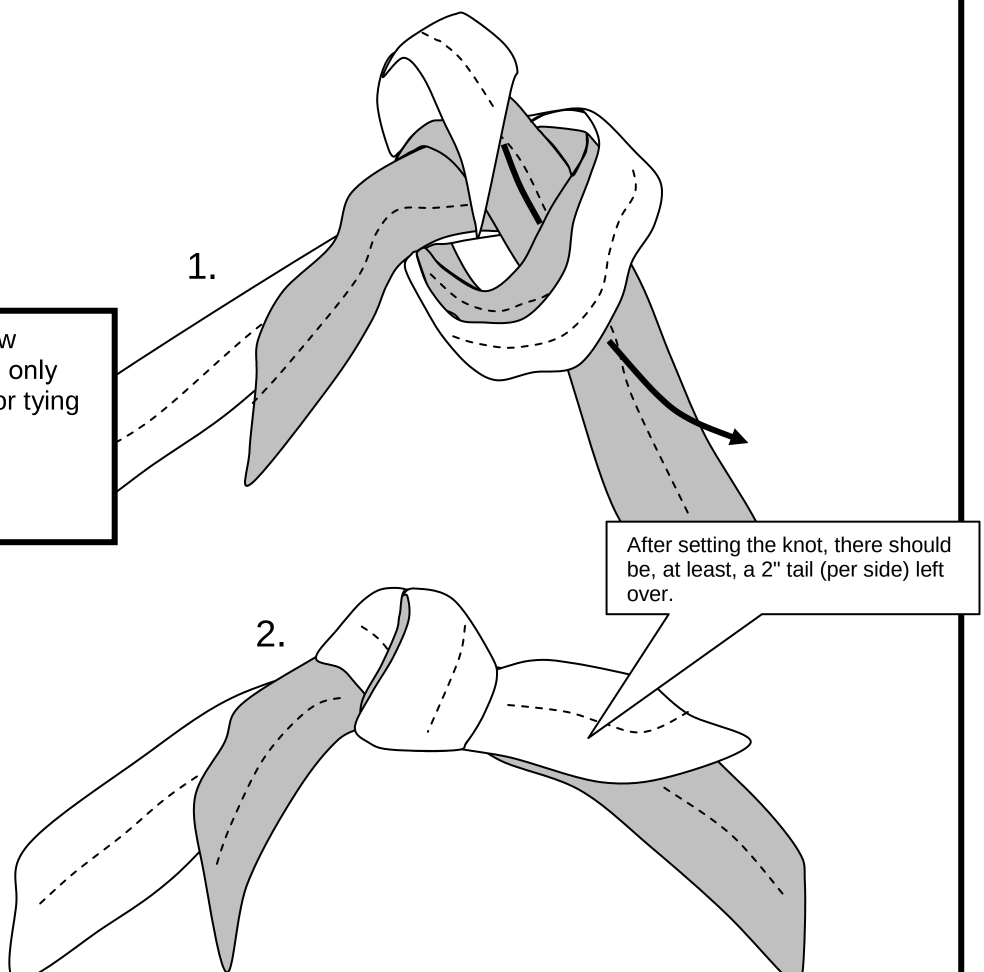
As with all knots, the overhand and the overhand on a bight have some interesting characteristics, with both, good and bad points, depending on the application. The overhand and the overhand on a bight have consistently tested very high in pull tests. A rope looses only approximately 15% of its strength when an overhand on a bight is tied.

The down side to the overhand is it becomes almost impossible to untie after it has been set with a heavy load (one person or greater). In addition, a single overhand <u>is not recommended</u> as a stopper knot, or as a back-up knot for other knots. The reason for this is, that a “hand” set overhand tied at the working end of a rope, tends to become loose over a period of time, and in some cases, may “self” untie. For back-up applications, as in backing the bowline, use a “double overhand” or a Yosemite back-up (see bowlines).

Overhand On A Bight

Overhand Follow Through Bend (Using Webbing)

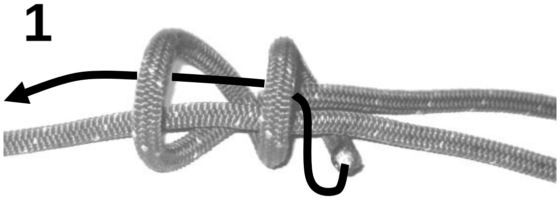
The “Overhand Follow Through Bend” is the only acceptable method for tying two working ends of webbing together.



The Double Overhand Follow-through Bend

This Bend is used to combine two working ends of rope, i.e. extending a line, or for making accessory cord loops. Some teams advocate a triple overhand bend. 3 overhands is over-kill, 2 will more than do the job.

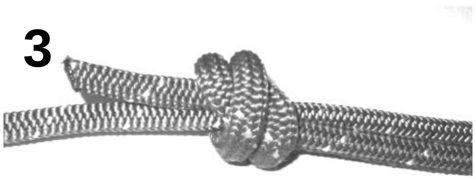
1



2

After the first Double Overhand is tied, rotate the entire ensemble clockwise and repeat the first three steps.

3



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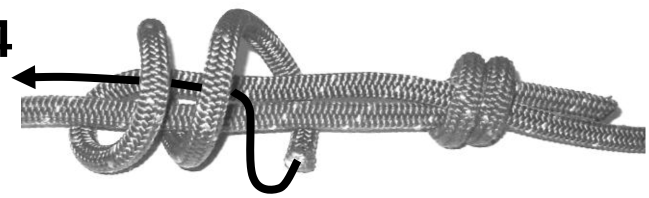

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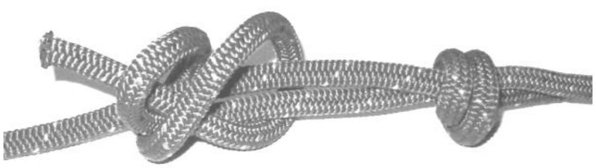

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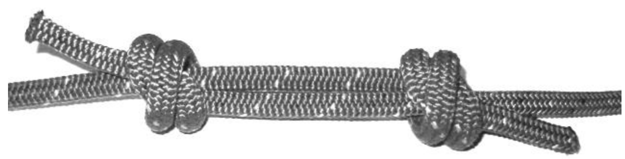


After the two Double Overhands are tied and the tails are pre-tensioned about 1 ½ " long (the tails will tension to about 1" in length when the bend is set), pull on the standing parts so that the two knots slide together as shown below in steps 7 and 8. When this bend is tied correctly, two inter-locking Xs will form on one side (7) and the other side will look parallel.

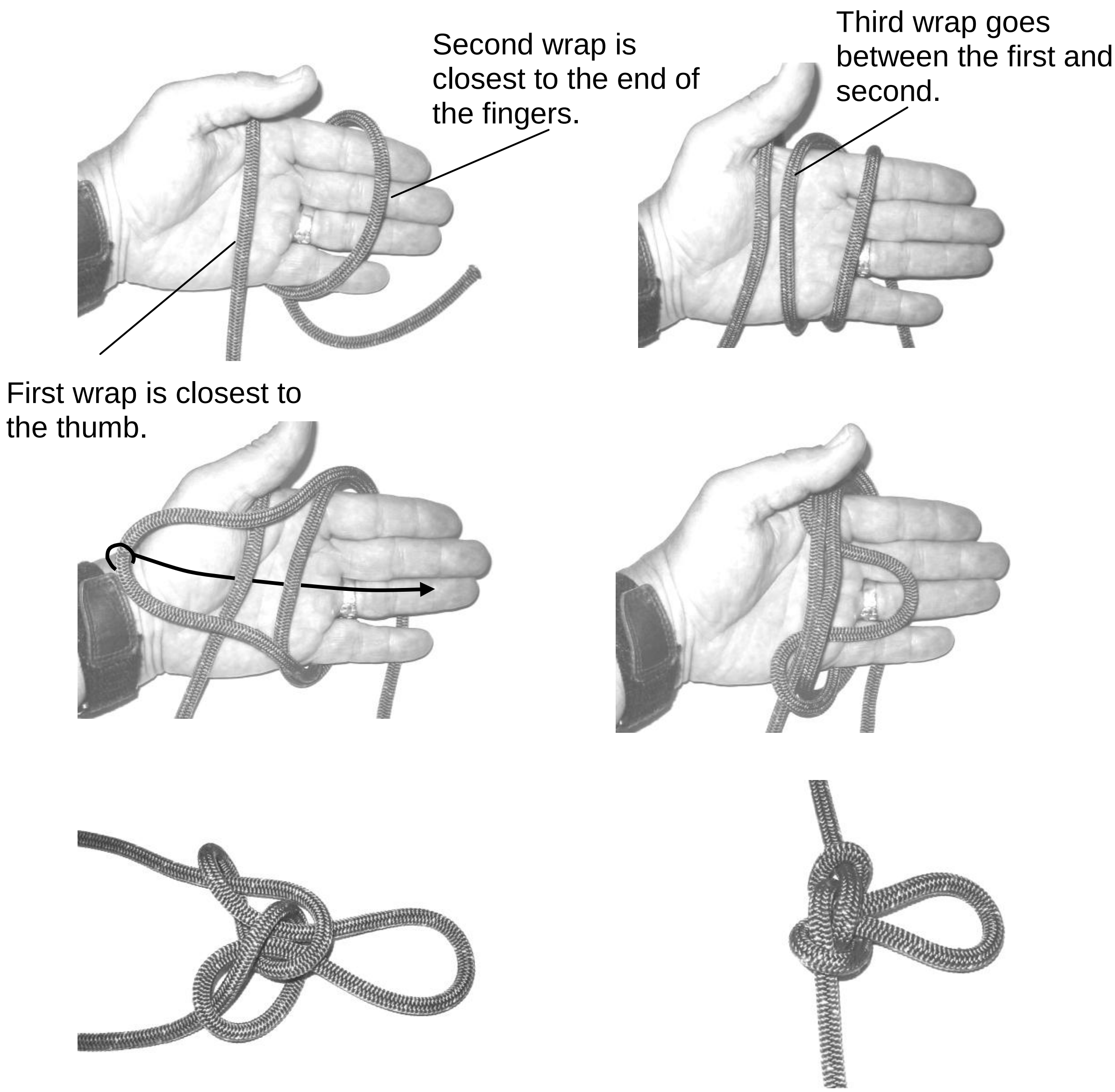
7

8

ne loop o

In addition to its mid-line qualities, the Butterfly has three distinct loops, when the knot is opened up, can be loaded in three different directions.

It is considered part of the overhand family, and it is a close cousin to the "Ashley Bend", the Striate Bend and the "Hunters Bend".



Butterfly Tied From a Bight

Many time it is preferable to tie the butterfly from a bight, this technique allows for a precise location of the final loop. This is a valuable tool when rigging multiple tensioned back-tie anchors as shown in the bottom photos.

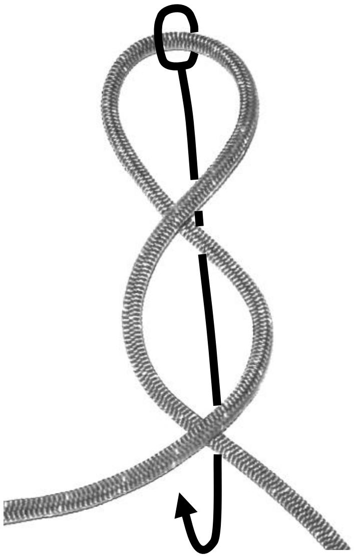
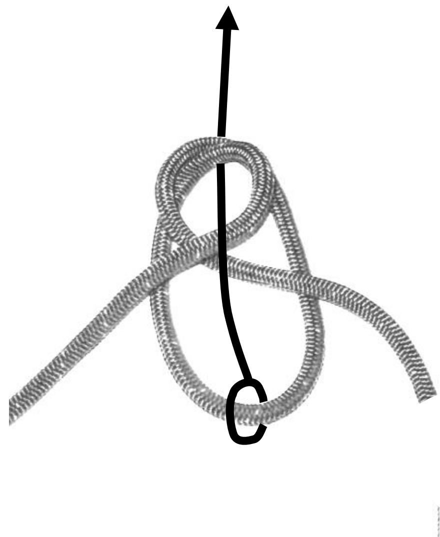
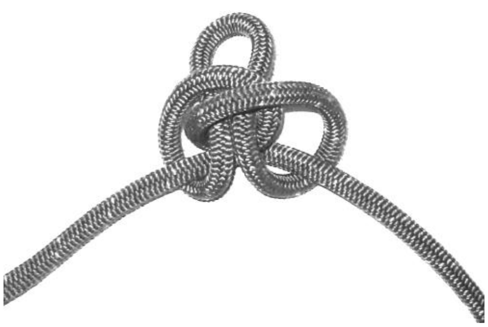
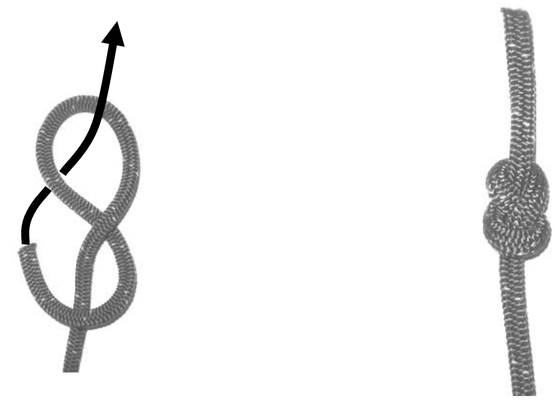





Figure Eight Family

Figure Eight, and the Figure Eight on a Bight

The *Figure Eight* is the base knot for the entire figure eight family of knots. The figure *Eight on a Bight* is one of the two most used knots (the other being the Bowline) for rescue anchoring.

Some notable advantages with the *Figure Eight*, and the *Figure Eight on a Bight* is that they are very recognizable, which makes mistakes in tying these knots obvious. In addition, the Figure Eight and the Figure Eight on a Bight are easy to learn and remember.



Although the *Figure Eight on a Bight* is a slightly stronger knot than the Bowline, the trade off is that the *Figure Eight on a Bight* is definitely harder to untie after being subjected to a heavy load. In addition, given equal loops, the gain of the Figure Eight on a Bight is double the size of the Bowline. Sometimes this is not a huge issue, but when working under a high directional, using ½" rope, every bit of working space counts.

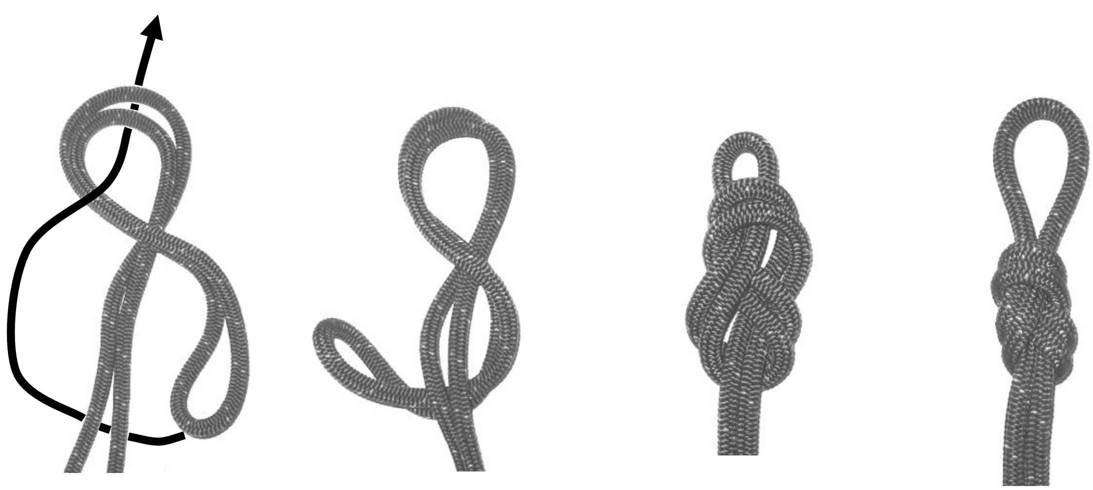
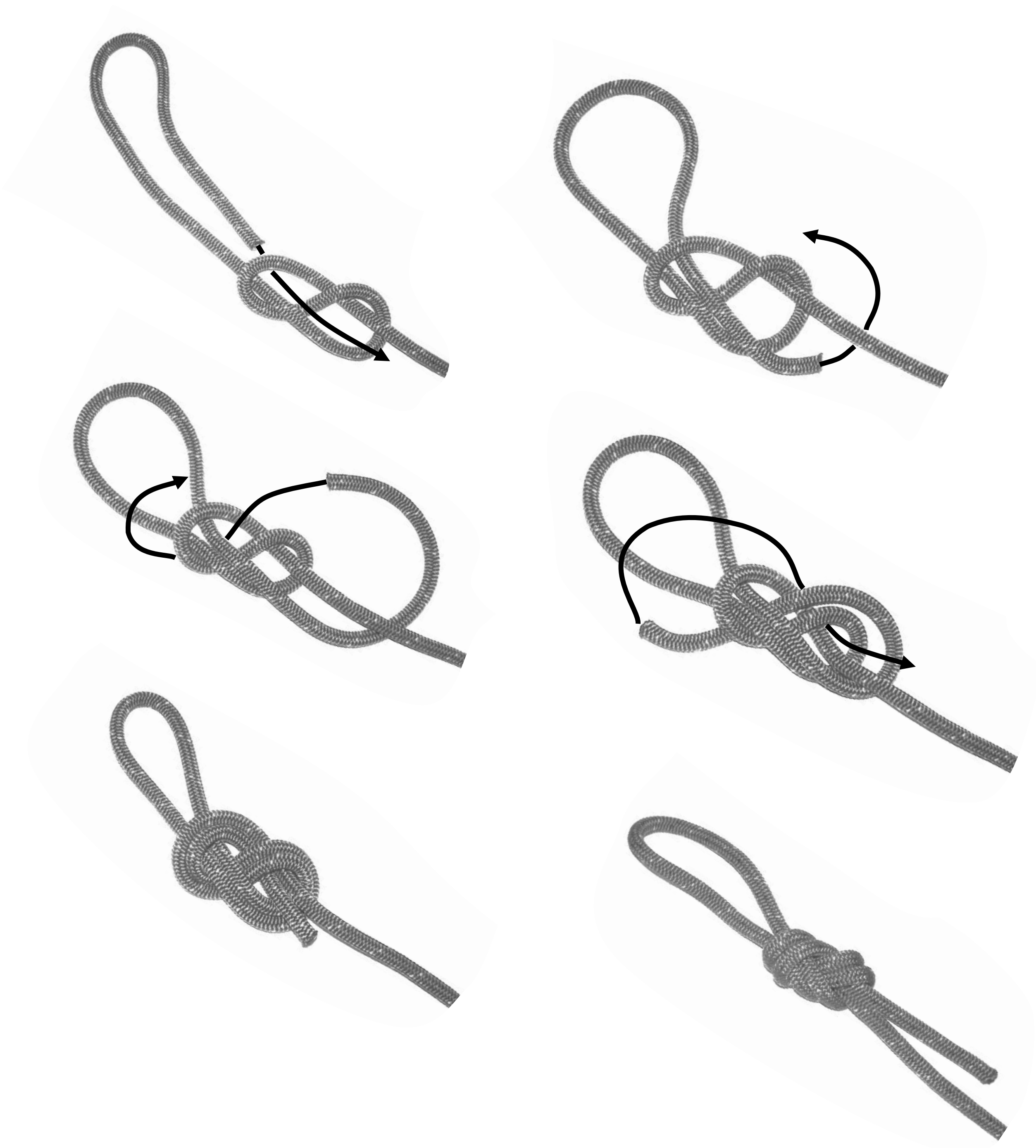


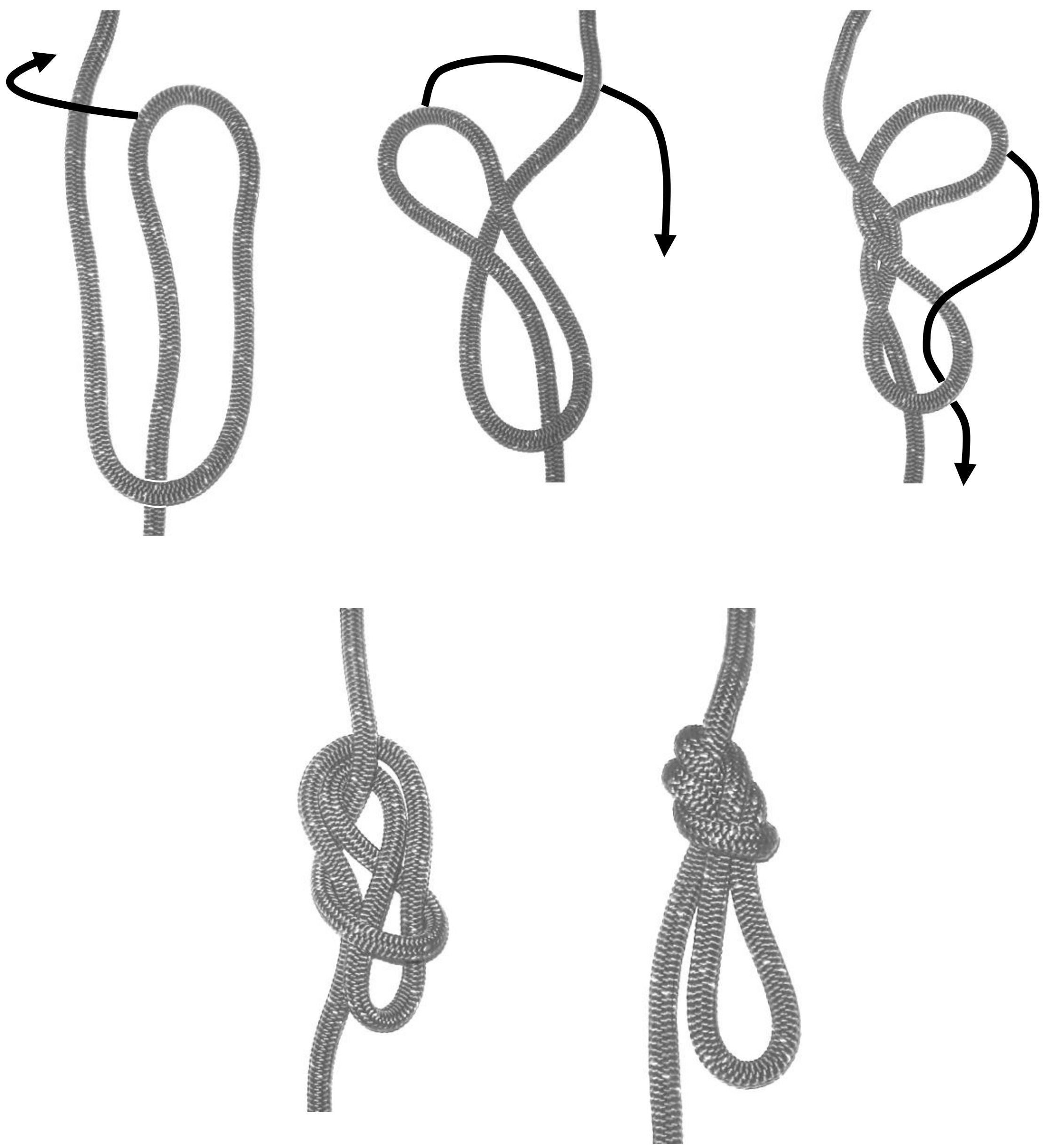
Figure Eight Follow Through

Although the end result of this knot is the same as the Figure Eight On a Bight, the way it is tied and it's function is much different. This knot is typically used when the need is to tie around an object. Care must be taken to correctly retrace the original Figure Eight. As with many knots, this knot is very susceptible to failure if it is not tied correctly.



Directional Eight or Inline Eight

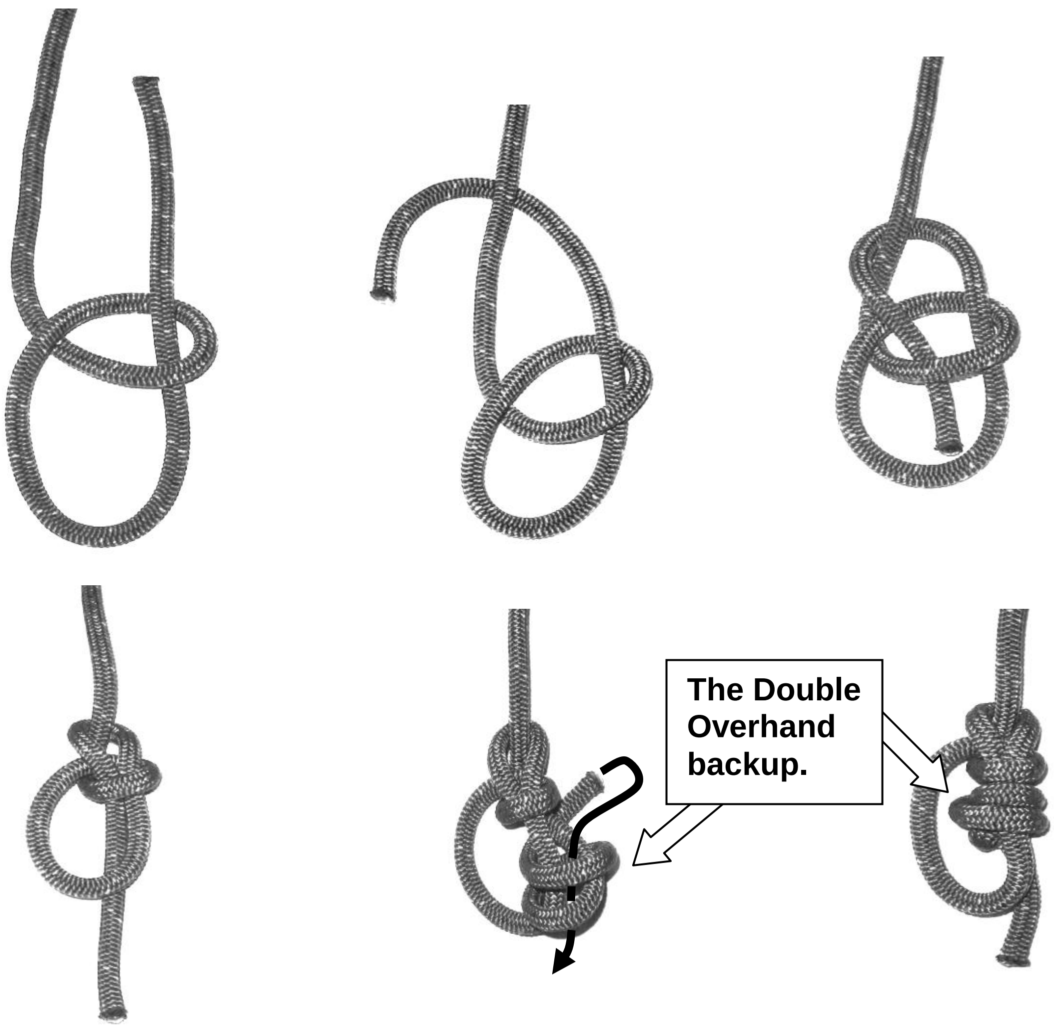
Another knot from the family of eights, the Directional Eight is very useful as the first step of an unequal Two Loop Figure Eight Follow Through (next page). This knot has lost some appeal as a midline knot for me personally because I do not feel it is as functional as the Bowline with a Bight, the Butterfly, and the Clove Hitch. Some of the inherit flaws with this knot is that it is extremely hard to untie after heavy loading, it may capsize if pulled the wrong way, and many people have problems tying it correctly.



The Bowline Family

The *Bowline* is the most versatile knot in rope rescue. Although not quite as strong as the “Figure Eight on a Bight” the *Bowline* is a strong anchor knot (Keep in mind that the difference in strength between these two knots will not affect the overall efficiency of a rescue system). The *Bowline* does have an advantage in that it is substantially easier to untie.

The *Bowline* is strong under tension, and susceptible to “self untying” when in a relaxed position, because of this fact, I will show two techniques I feel are the most suitable for this purpose, the Double Overhand back-up, and the Yosemite back-up (also known as a retrace).

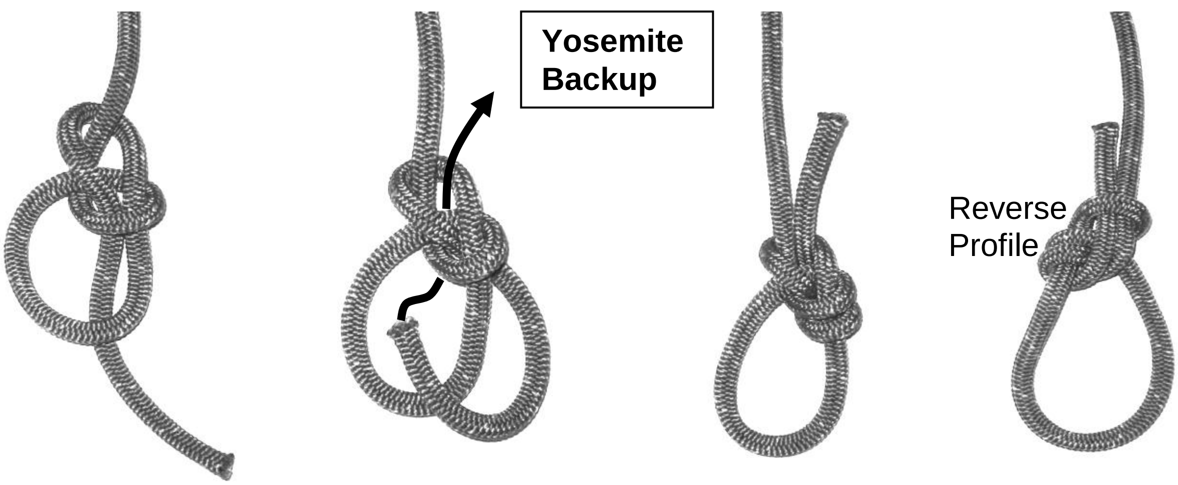


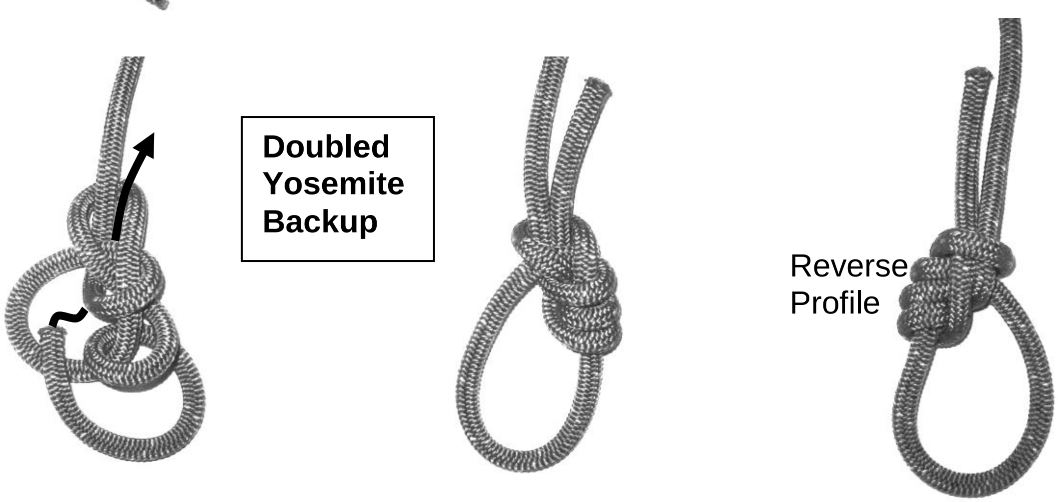
Yosemite backup to the Bowline (Yosemite Bowline)

As I stated earlier, the Bowline needs a backup knot. Under tension there are no problems with the Bowline (even with dynamic rope). It is during those times when the Bowline is in a relaxed position that it becomes susceptible to coming undone, mandating a backup. Note, the Double Long Tail Bowline does not require a backup because the long tails that are used as secondary attachments for the rescue package keep the knot from undoing.

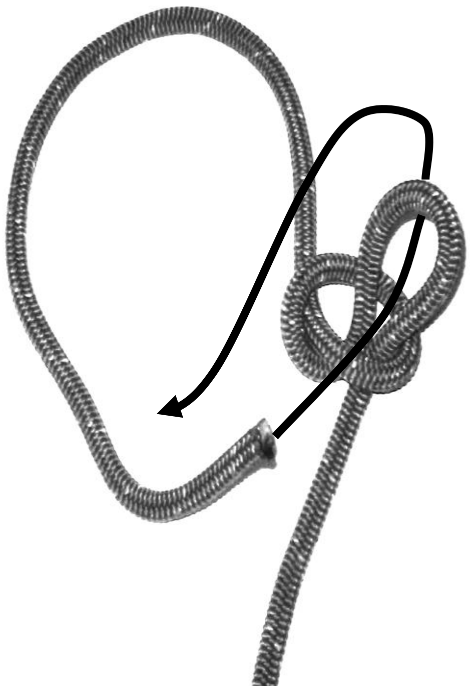
The Double Overhand Backup is the most secure backup (shown on the previous page). The Double Overhand also adds more bulk to the loop of the Bowline; this is what makes the Yosemite backup so popular. It is much cleaner, keeping the loop free, and it is also very reliable.

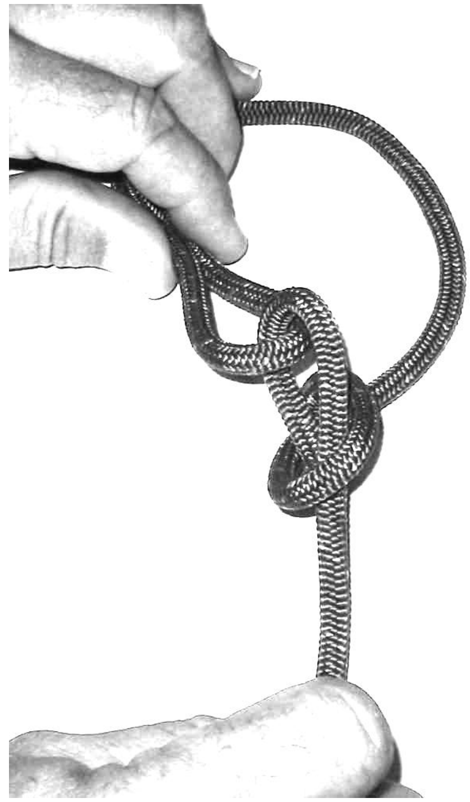
The Yosemite is my favorite backup, but I have noted with dynamic rope and some static rope that even the Yosemite does not completely lock, still giving the bowline a spongy feel and wanting to untie. It is with this type of rope that I will tie a Doubled Yosemite.

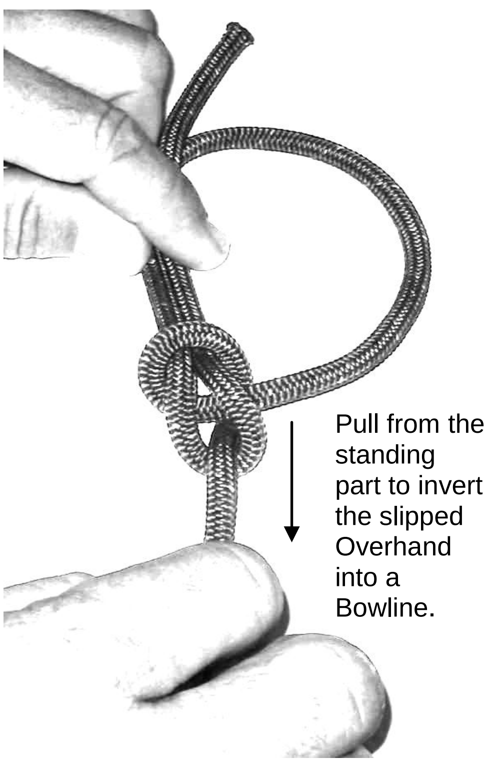




Snap Bowline/Climber's Bowline







Snap Bowline/Climber's Bowline

The Snap Bowline, also known as the Climber's Bowline, is nothing more than a nick name that defines a specific way to tie the knot.

This is a graphic example of how the Bowline is an inverted slipped Overhand. Indeed, this method of tying the Bowline takes advantage of this fact.

This technique works well when facing an anchor or an object that you must be tie the Bowline to. It is extremely quick, and makes the initial adjustment of the loop very easy.

The Bowline With A Bight

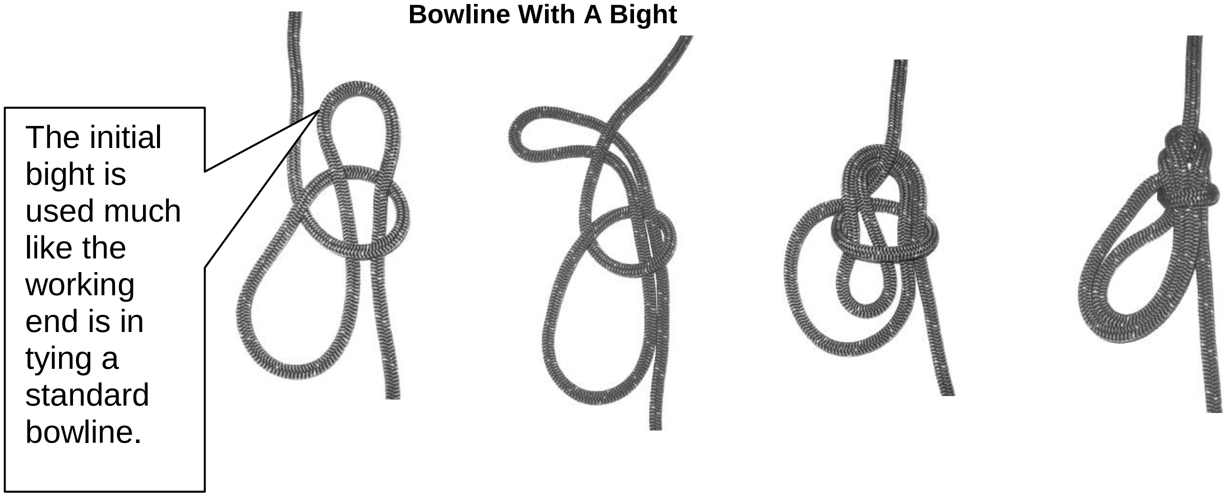
The *Bowline With A Bight* is a great mid-line loop. It is easy to tie, untie, and is very recognizable.

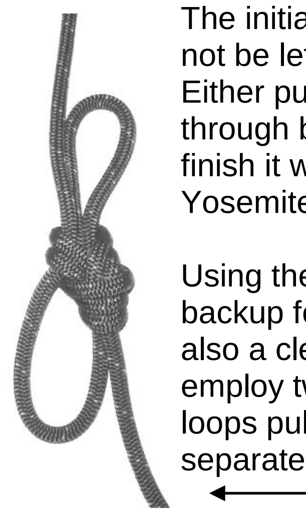
The *Bowline With A Bight* rivals the “Butterfly” for a mid-line loop(s), not as easy to tie as the “Butterfly”, but flows better in the direction of pull.

The *Bowline With A Bight* has all but eliminated The “Bowline On A Bight” because it is definitely more usable, and it has no problem with shearing.

There is the potential for problems if the loop created by the initial bight is pulled in the opposite direction of the intended flow of the knot. The *Bowline With A Bight* may invert and turn into a slipped overhand, because of this, the *Bowline With A Bight* must have a carabiner through both, the main loop, and the loop created by the initial bight, or it must be backed up like the standard bowline.

Bowline With A Bight





The initial bight should not be left unsecured. Either put a carabiner through both loops or finish it with a Yosemite backup.

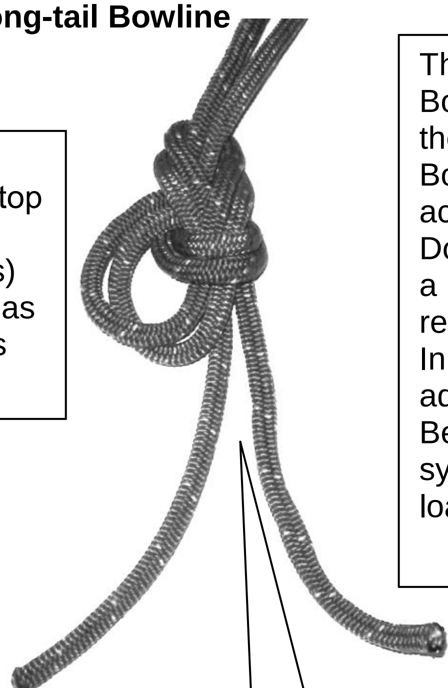
Using the Yosemite backup for this knot is also a clever way to employ two secure loops pulling in separate directions.

Doubled Long Tail Bowline

The *Doubled Long Tail Bowline* is used in creating the yoke, the culmination point at the rescue end of the main line and the belay line.
The yoke is the point of attachment for the rescue adjunct, i.e. high angle/steep angle litter attachment, and “team based pick-off” rescue package attachment.

The doubled bowline is the adjunct attachment point, and the long tails are secondary attachment points for the rescuer and victim. The long tails may be tied at any length to meet the need of the type of adjunct used.

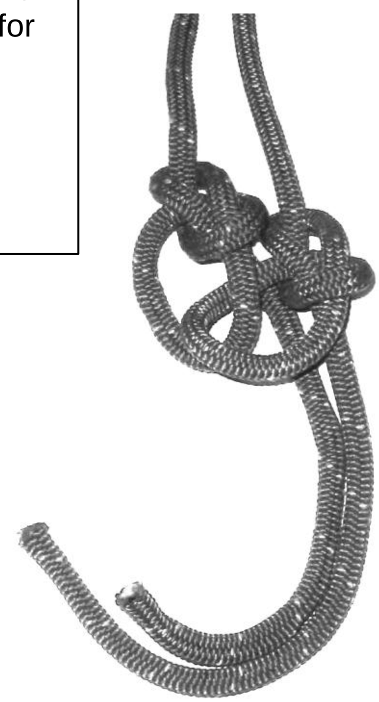
Doubled Long-tail Bowline



Keep the “gain” (the top to bottom dimensions) of the knot as compact as possible.

The long tails may be adjusted to meet the secondary attachment needs of the rescuer and victim.

The Inner-woven Bowline (Also known as the Inner-locking Bowline) is also quite acceptable. I find the Doubled Long-tail to be a little cleaner and more recognizable. Yet, the Inner-woven allows for adjustability of the Belay line after the system has been loaded.

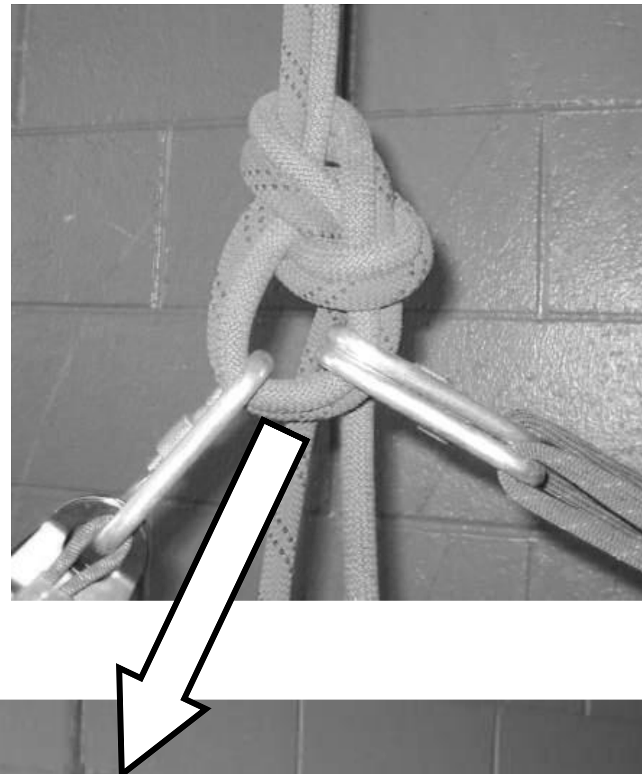


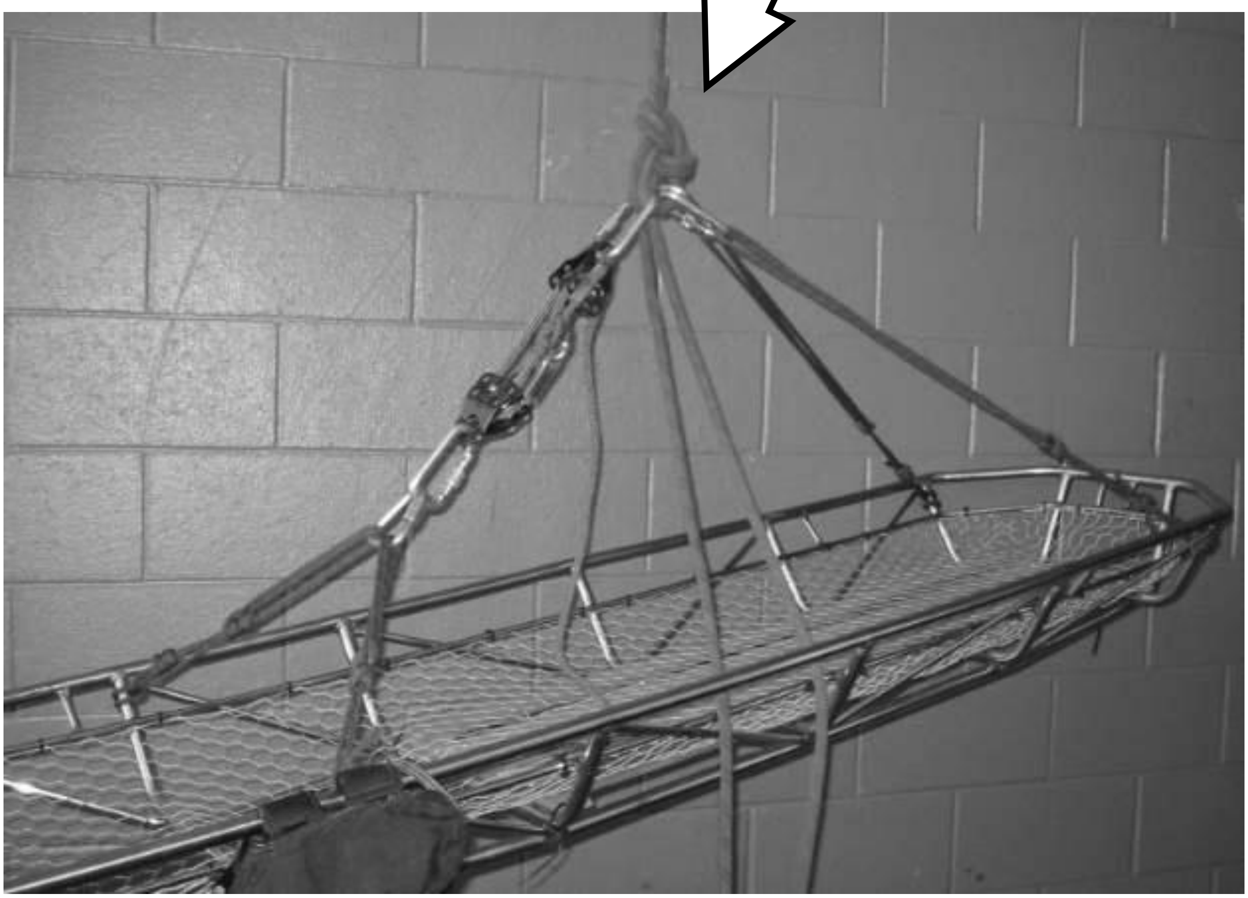
Inner-woven Bowline

The Doubled Long-tail Bowline is the perfect knot for a collection point for team based rescue adjuncts, easily and safely loaded in multiple directions.

This knot is half the gain of a Figure Eight on a Bight, allowing for added space under a high directional anchor system.

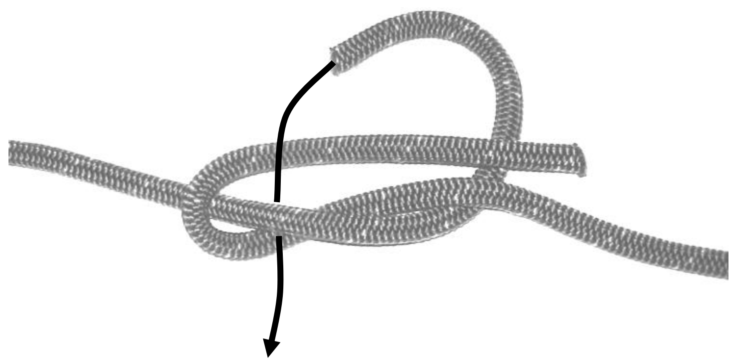
The Bowline is substantially easier than the Figure Eight on a Bight to untie after it has been used for system loads.

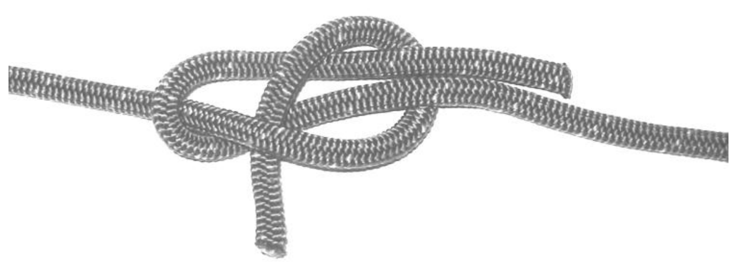


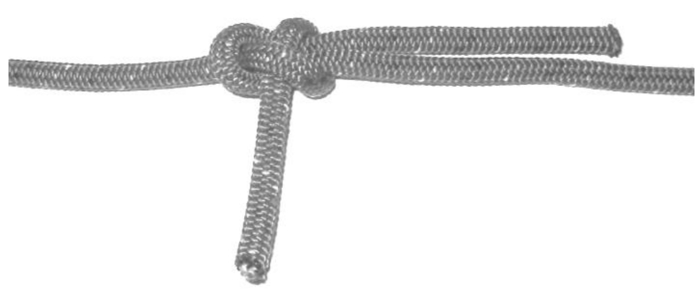


Becket Bend
With one good look you can see why the Becket Bend is considered a part of the Bowline Family. It is the same basic formation, with the difference being, the Bowline creates a loop, and the Becket Bend brings two ends of rope together.

As with the Bowline, the Becket Bend is very secure, yet easy to untie after it has been set. Also, (same as the Bowline) the Becket Bend must be backed up when it is used to support a live load.







Double Becket Bend

The Double Becket Bend is a more secure bend than the (single) Becket Bend because of the round turn that captures the bight of the opposite rope. Although many knot experts claim the Double Becket Bend is secure enough by itself, we still maintain the Double Becket Bend needs back-up knots as well.

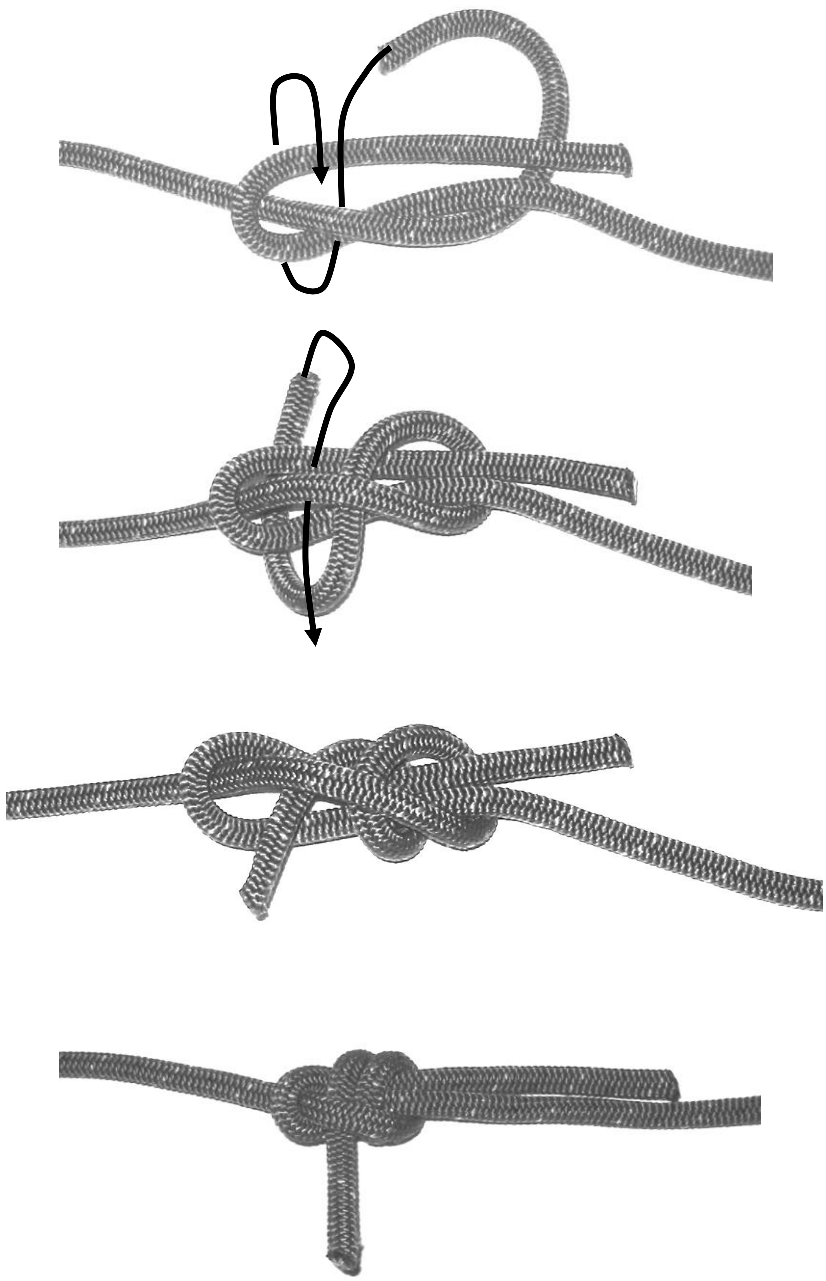
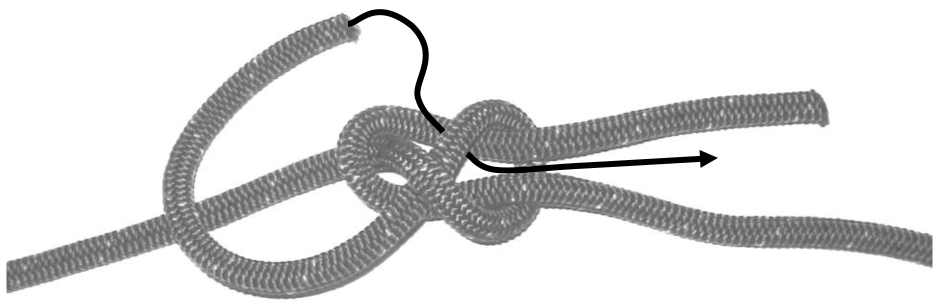
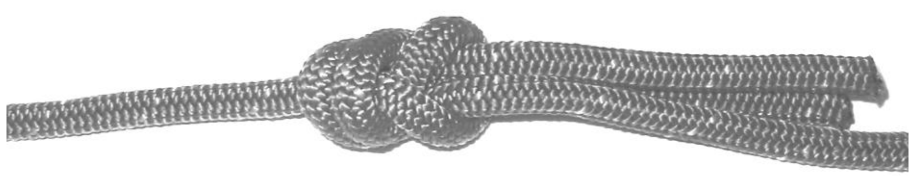


Figure Eight Becket Bend
The Figure Eight Beck Bend is nothing more than a method of backing up the Becket Bend and the Double Becket Bend. It most likely got its name because of the resemblance the back up has to a Figure Eight.

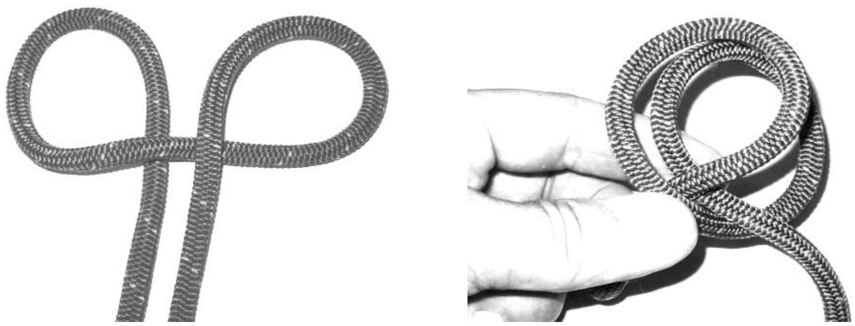




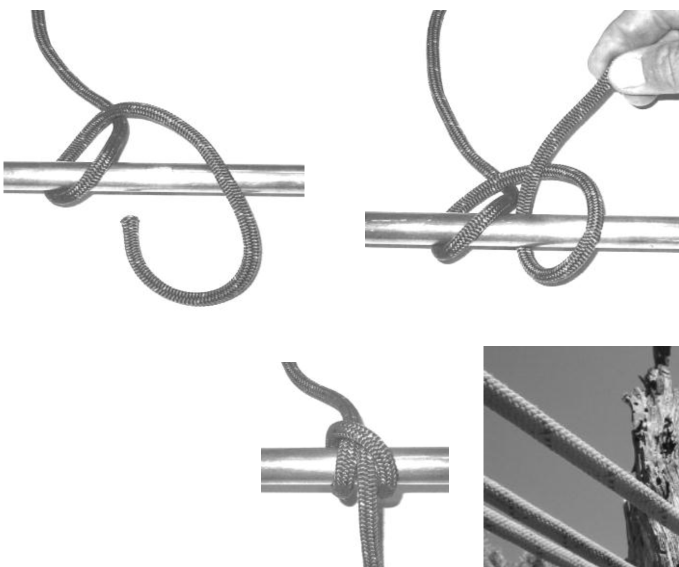
Hitches

Hitches are a type of knot that, for the most part, is dependent on a host object for maintaining its form and function. When the host object is removed from the hitch, or the hitch is removed from the object, the hitch will come apart.

Clove Hitch

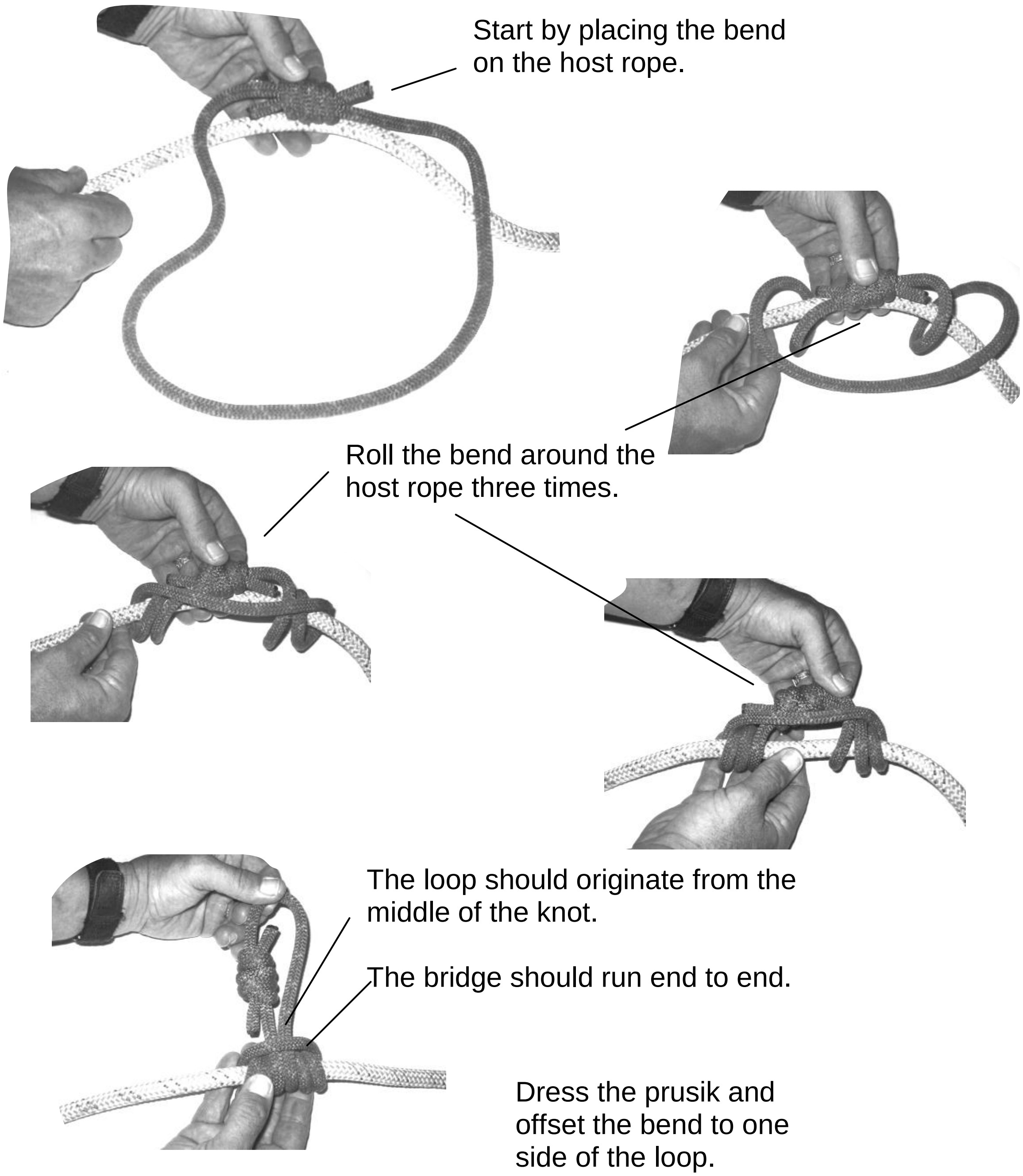


Clove Hitch Tied Around an Object



Prusiks

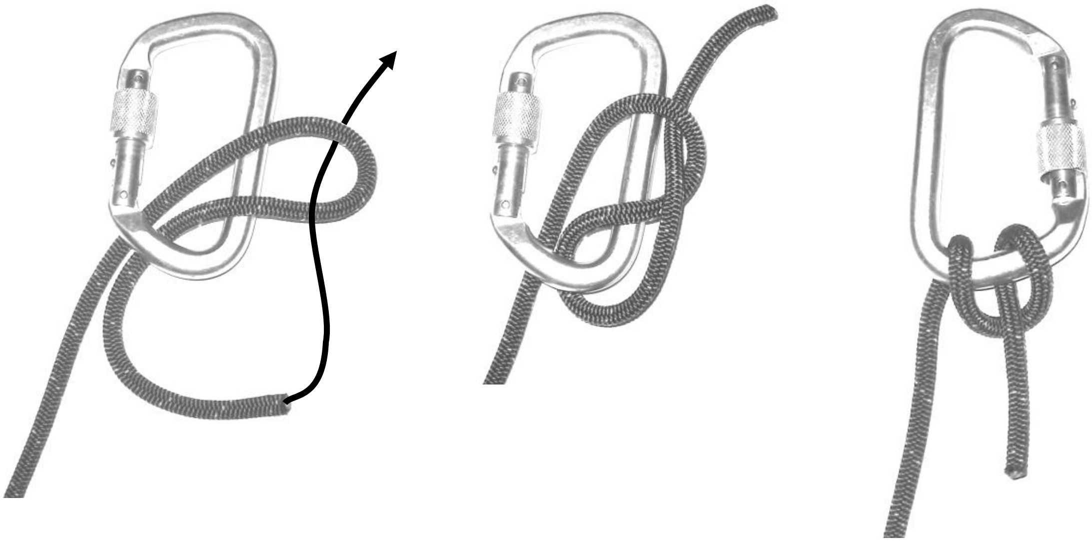
Prusiks, without a doubt, are the most used hitch in rescue work. The Prusik is used in everything from personal attachment points for ascending, to system uses such as Tandem Prusik Belays, and Haul Prusiks for mechanical advantages. The ability to tie the prusik correctly is a must for all rope rescue personnel.



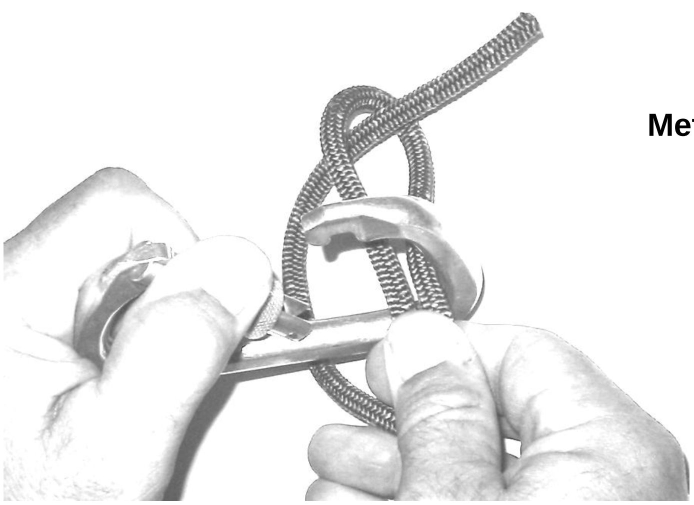
Munter Hitch

The “Munter Hitch” may be used as a single person belay, it is also an important part of the Load Releasing Hitch.

Method 1

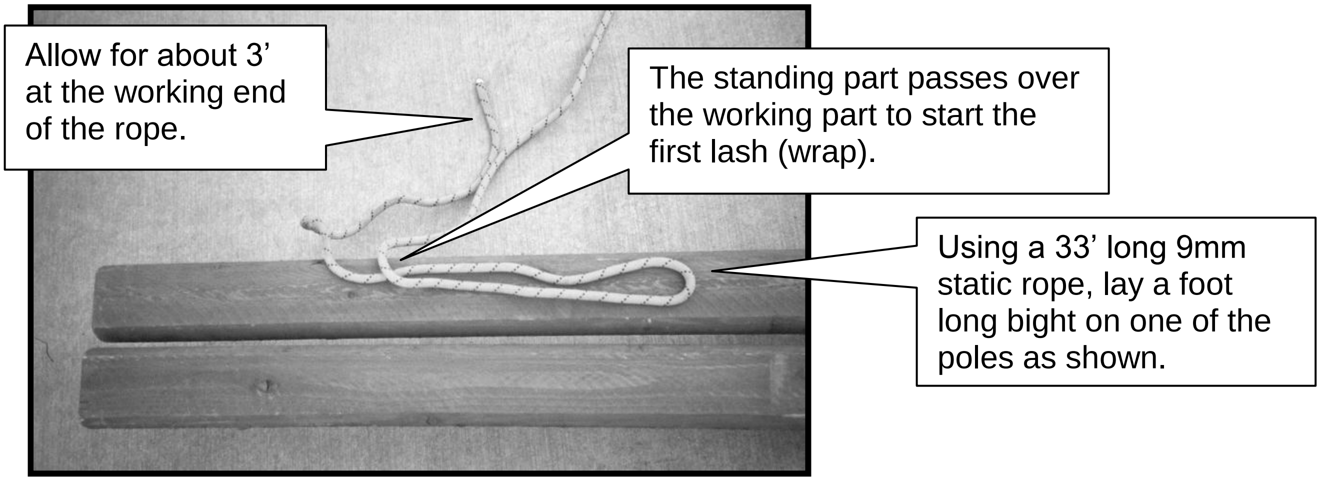


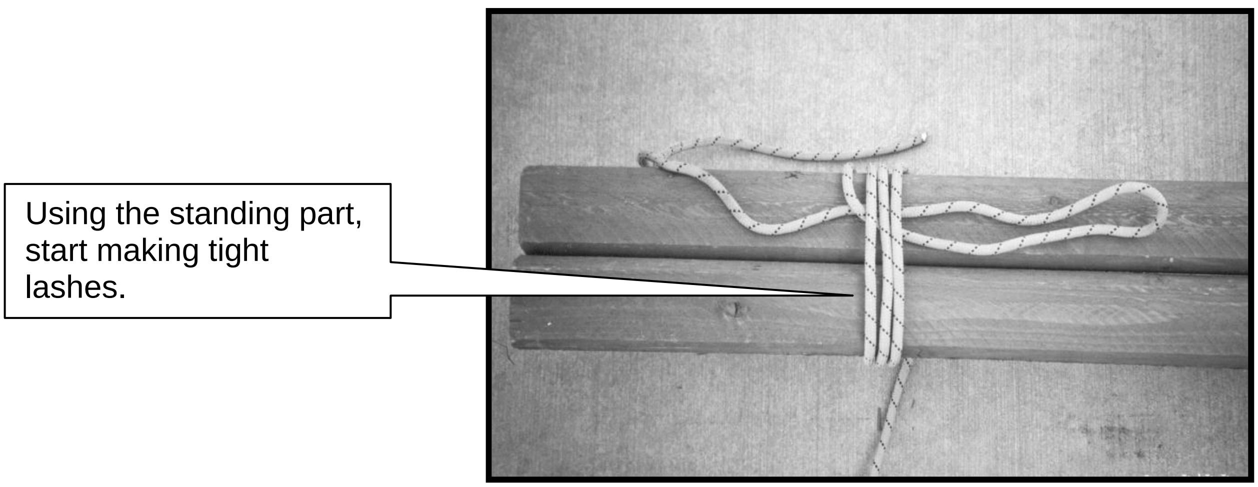
Method 2

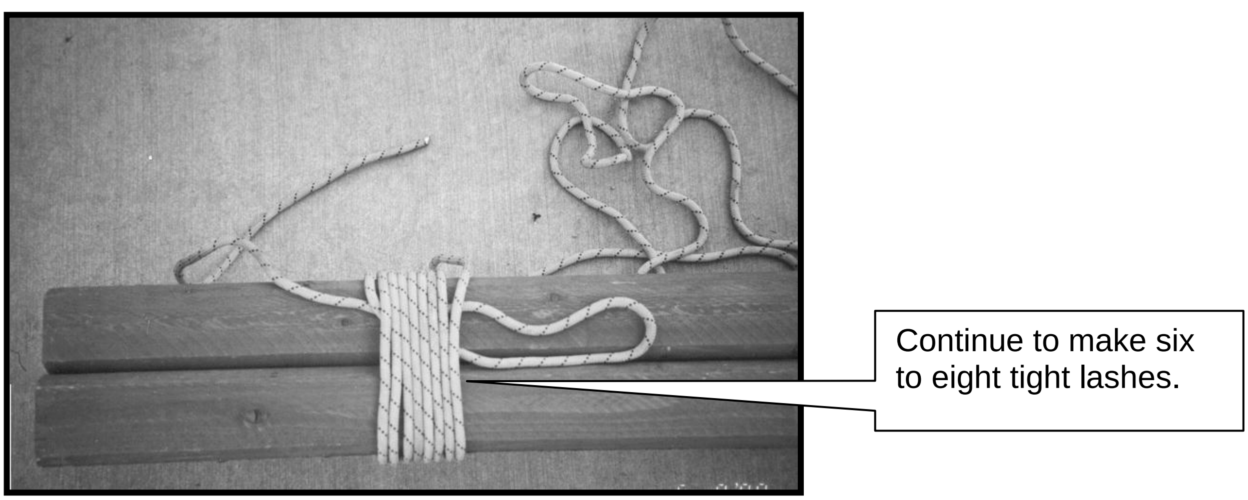


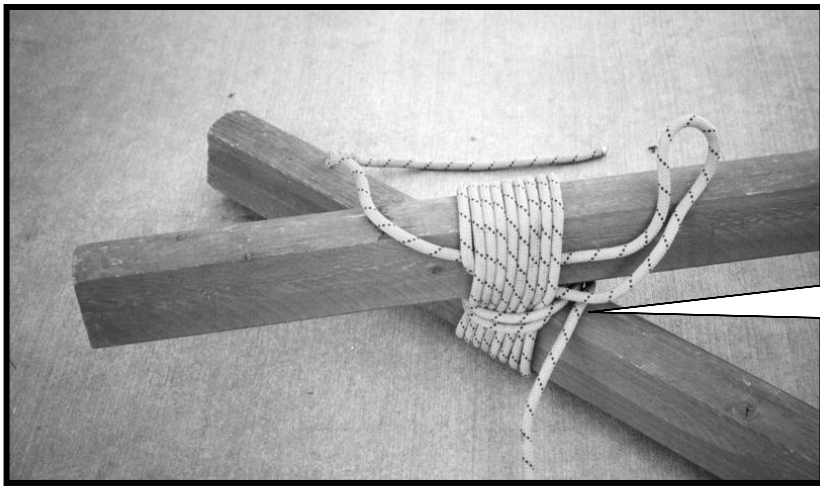
Lashing and Frapping

Lashing and frapping is an important knotting skill in the construction of high directionals, typically seen in conjunction with “A” frames.



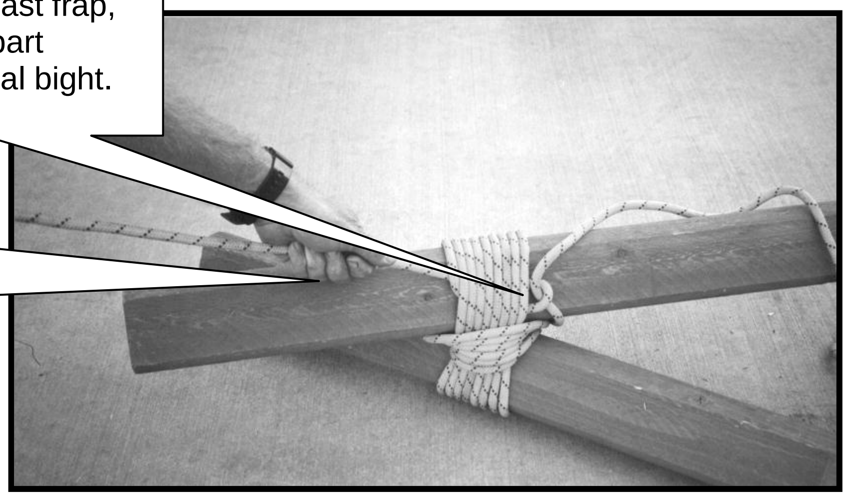




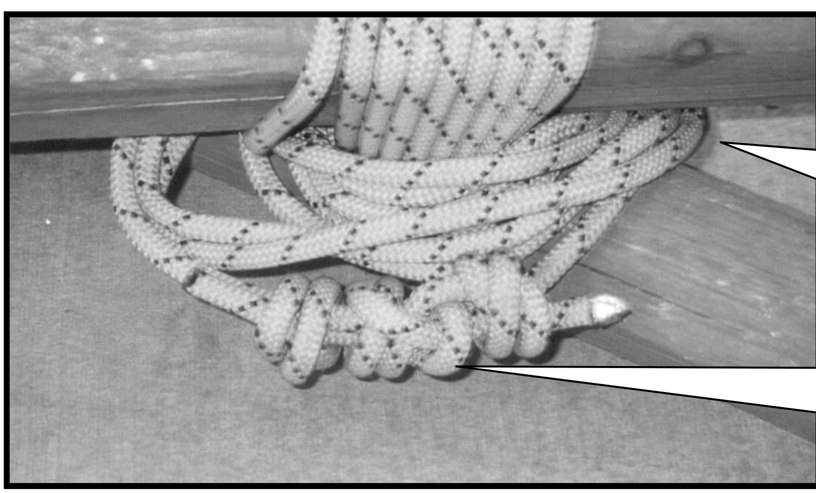


Open the poles, and start making six fraps (the middle wraps of the system).

After making the last frap, put the standing part through the original bight.

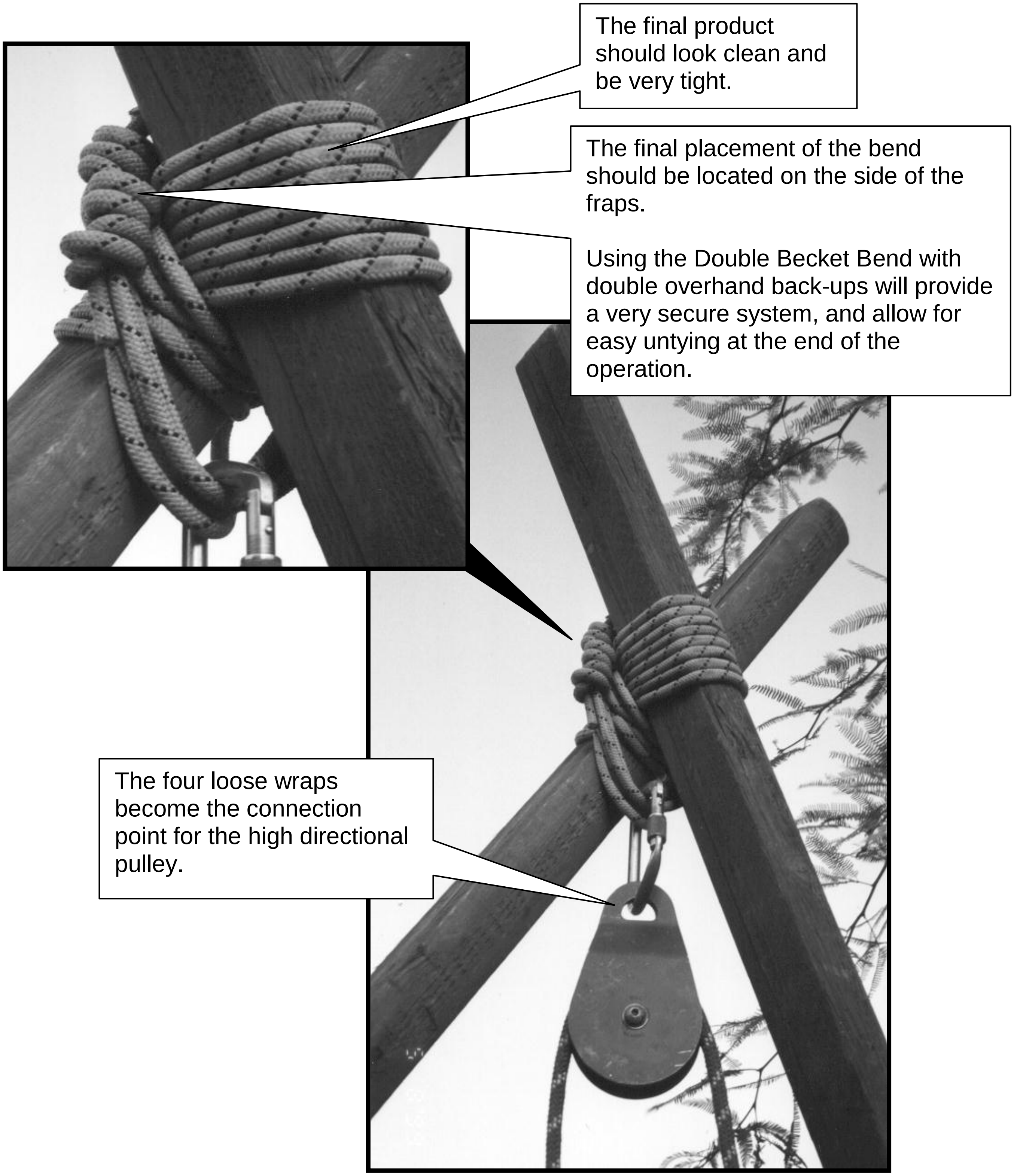


Lock the standing part by pulling the working end, and jamming the standing part behind the lashes.



With the remaining rope, take the two ends and loosely wrap them in opposite directions (There should be about four loose wraps.)

Finish the two ends by tying a Double Becket Bend and back each end with a Double Overhand.


The final product should look clean and be very tight.
The final placement of the bend should be located on the side of the fraps.
Using the Double Becket Bend with double overhand back-ups will provide a very secure system, and allow for easy untying at the end of the operation.
The four loose wraps become the connection point for the high directional pulley.

Chapter 5, Anchors

Anchors are the most critical component of any rope rescue system. The entire rescue is in jeopardy if the anchors are not reliable. Anchor systems are made up of two major elements; 1-choosing the best anchor (i.e. boulders, vehicles, trees, and bolts), and 2-rigging the anchor. Building an anchor system requires much practice and experience.

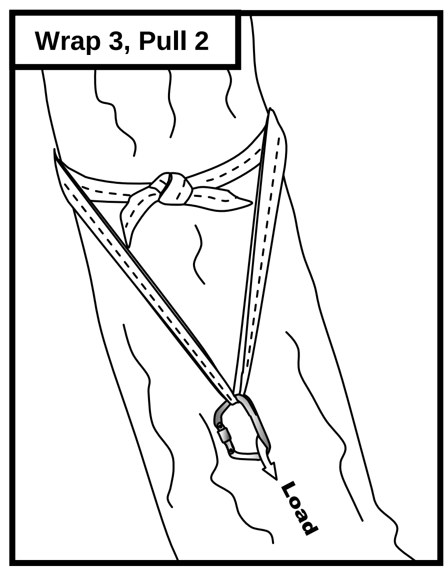
When dealing with structures, chose anchor points which are part of the inherent structure of the building. This includes columns, beams, anchors for window cleaning equipment, and elevator housings. Avoid corroded metal, weathered stonework, and deteriorated mortar. Avoid using vents, flashing, gutters, and chimneys.

When using a vehicle for an anchor, remove the ignition key, set the brake and chock the wheels. Do not use the bumper. Connect directly to the vehicle frame using such items as the axle, cross member or tow hooks.

Often a desirable anchor is off to the side of a needed direction of pull. Ideally, they should be directly above and close to the fall line. When this is not possible (which seems to be more times than not) advanced anchor rigging skills come into play, namely, focusing the direction of the main anchor to a viable position.

Wrap 3, Pull 2

Based on the diameter of the anchor, select an appropriate length of webbing, wrap the webbing around the anchor 3 times, and tie an overhand follow through bend with it's ends. Dress the wraps in a way that will position the bend on the first wrap and next to the anchor, pull the remaining two wraps and attach a steel carabiner (with the gate pointing down hill from the anchor). Attach the next link of the system to this carabiner, i.e. anchor plate, figure 8 on a bight, systems rack or tandem prusik belay.

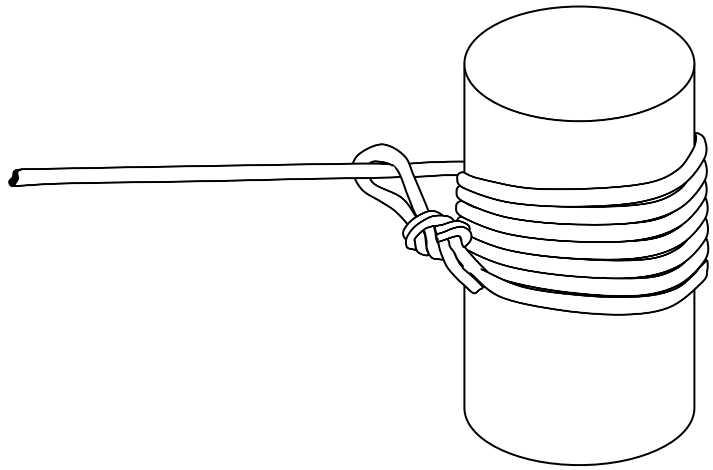


Rope may be used in place of webbing when wrapping very large anchors, i.e. a boulder ten feet in diameter.

High Strength Tie-off

A high strength tie-off is used when maximum strength of the rope is needed, i.e. highline operations.

The "high strength tie-off" is made by wrapping the line enough times around a "bombproof" anchor to take the tension off the knot on the last wrap. The smaller the diameter of the anchor the more wraps of the rope is needed.

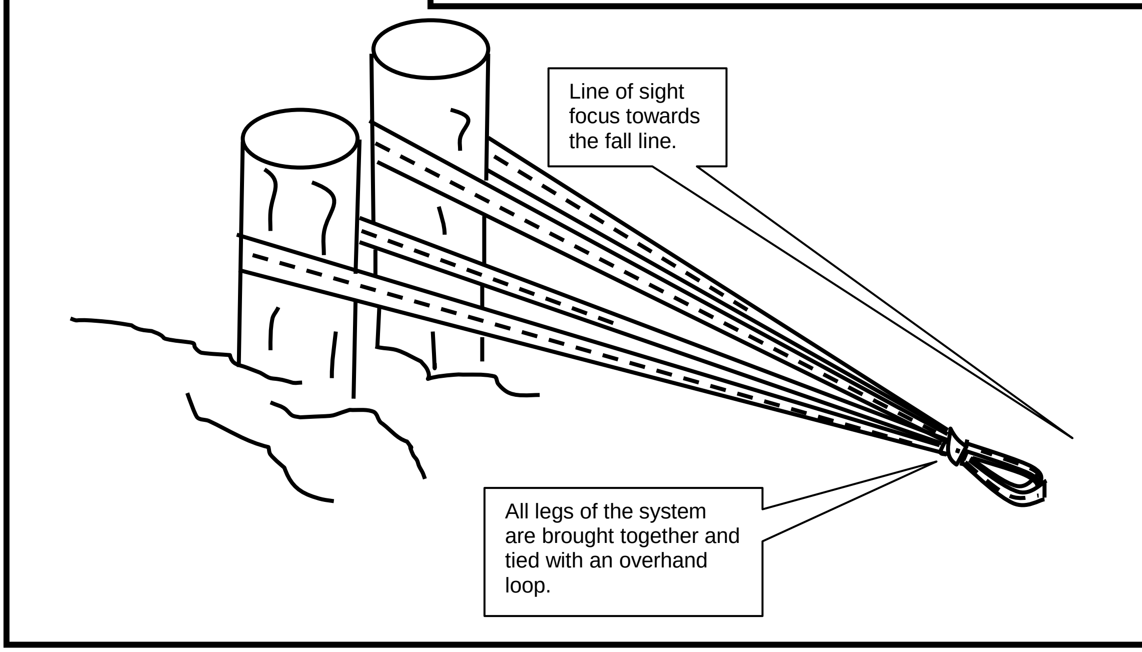


Tie a "figure 8 on a bight" or a "bowline" on the working end of the rope, and connect this knot to the standing rope just in front of the first wrap by using a steel carabiner. It is also acceptable to simply tie the tail of the last wrap around the standing part of the rope.

As a rule of thumb for a high strength tie-off, avoid using anchors that are less than 3 inches in diameter.

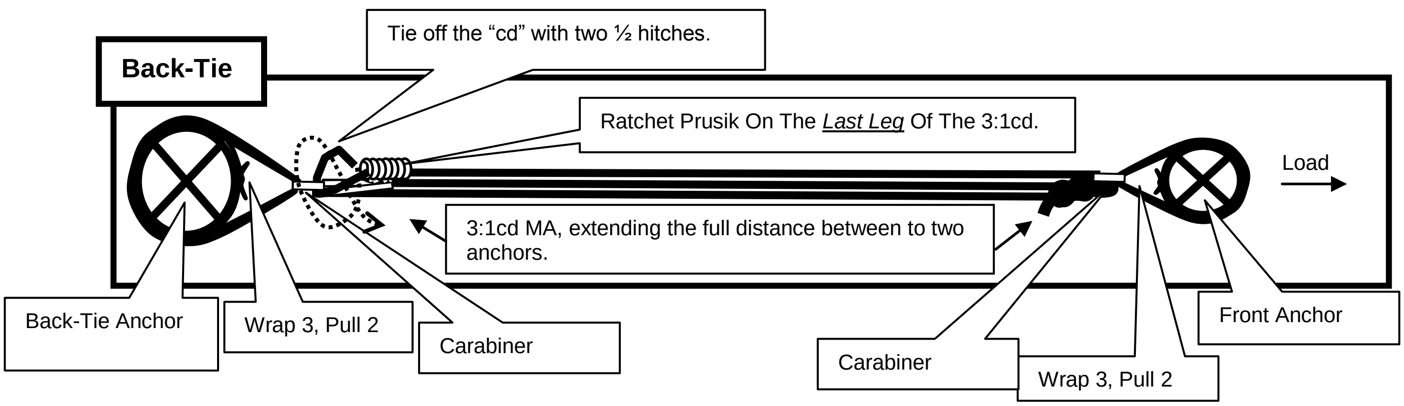
Fixed Multi-point Anchor System (Load Sharing)

Fixed Multi-point (Load Sharing)
Like a self equalizing system, load sharing is used to combine multiple marginal anchors to one focused point. In addition, load sharing is also useful in taking two solid anchors to focus a more desirable location for the fall line.



Back-ties

Sometime a questionable anchor, that has a preferable location to the fall line, can be used by anchoring that questionable anchor to a bombproof anchor. This is done by back-ties, typically using the wrap 3, pull 2 technique on both anchors, then connecting the two anchors by using a 3:1cd MA. All 3 legs of the MA should extend the full distance between the front anchor and the back anchor. By using this full length MA, rope stretch in the "back-tie" will be kept to a minimum. Note in the diagram below that the ratchet prusik is applied to the last leg of the MA. (in a normal MA setup, the ratchet be would on the first leg, closest to the load) By doing this, all three legs of the MA are tensioned. *Given that the purpose of utilizing three legs of tensioned rope is to mitigate rope stretch and that MA efficiency is of little concern in this application , carabiners should be used in place of pulleys.*

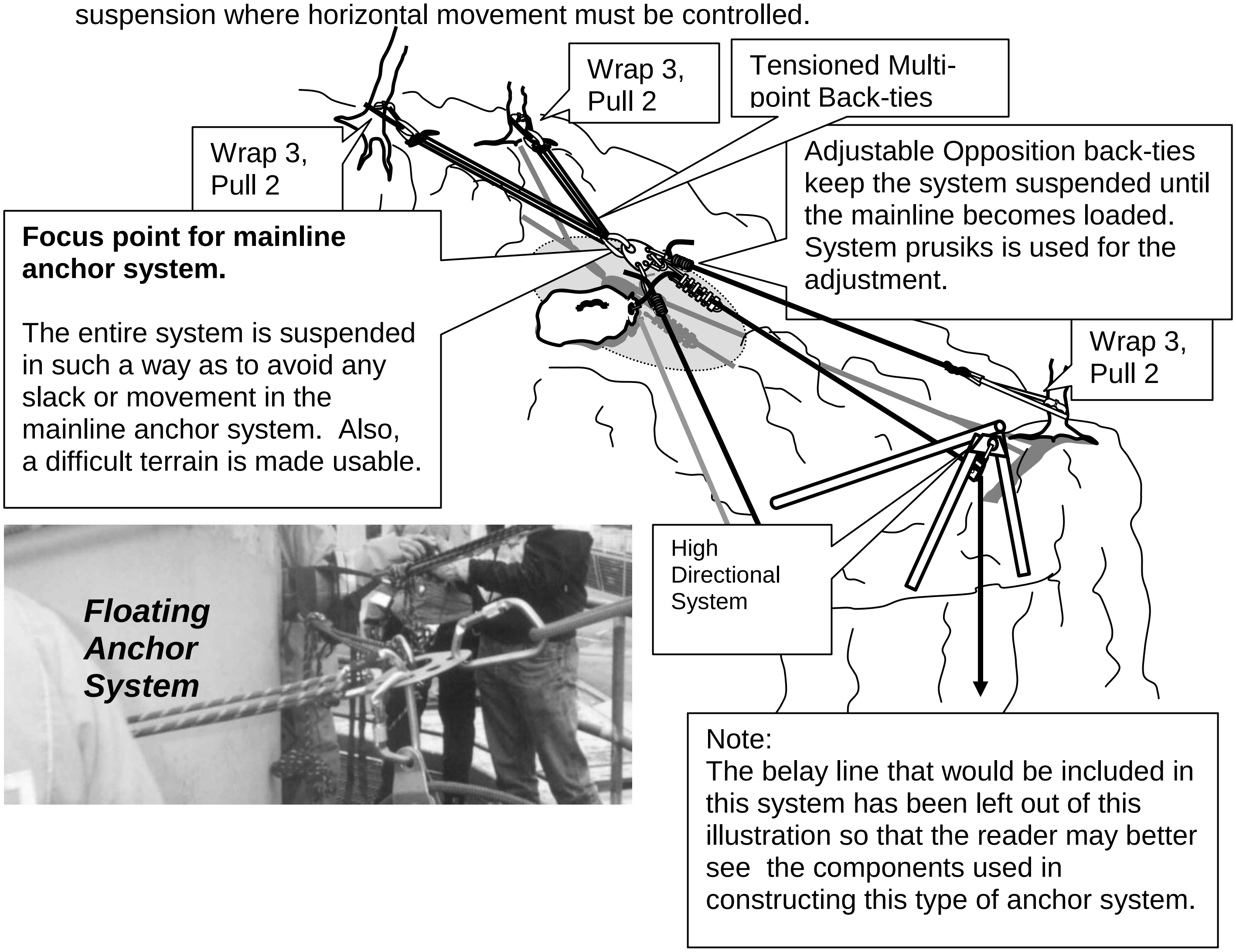


Opposition anchors
Opposition anchors do what their names imply, that is, they pull opposite of the direction of activity. Opposition anchors are often used to secure high directional systems such as “A” frames and “gin poles”.

Opposition anchors are also important in supplying a forward force to “Floating Anchors”, allowing the floating anchor to hold position with no slack in the main anchor legs.

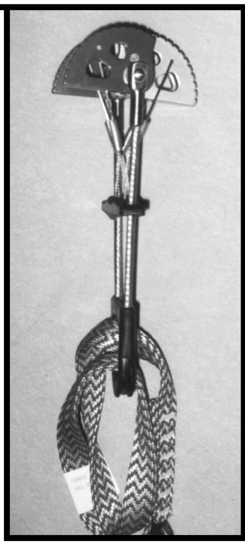
This forward force continues until the force of the rescue operation becomes greater. When this occurs, the opposition anchor system may become slack, this flexing of the system is considered normal.

Floating anchors
Floating anchors are constructed in harmony with the combination of multi-point, back-ties, and opposition anchors. Typically, these anchors are focused in a needed position where no natural anchors are to be found. In addition, floating anchors provide suspension where horizontal movement must be controlled.



Artificial Anchors,
Cams, Tapers, Hexentrics, and Bolts

Spring-Loaded Camming Device

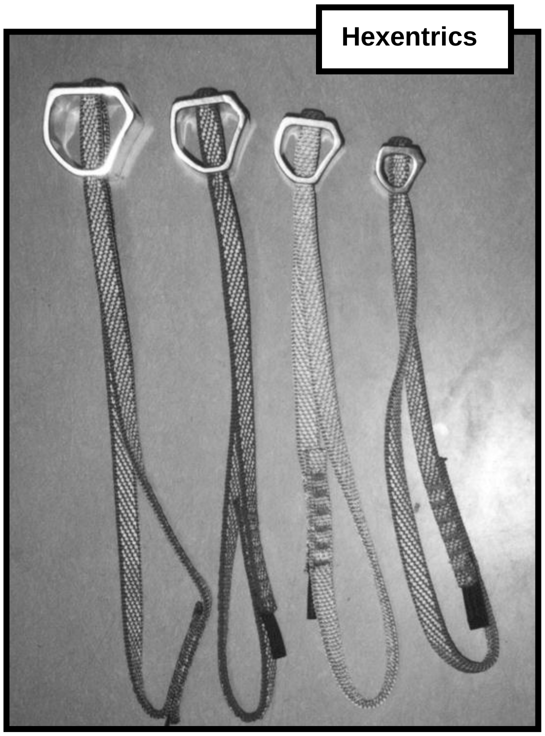


Although natural anchors much preferred for their expediency and strength, there will come the time when there are simply little to no viable natural anchors during the course of some rescues. It is these times we will turn to the use of artificial anchors. When used in the correct manner, a multi-point bombproof anchor system can always be constructed.

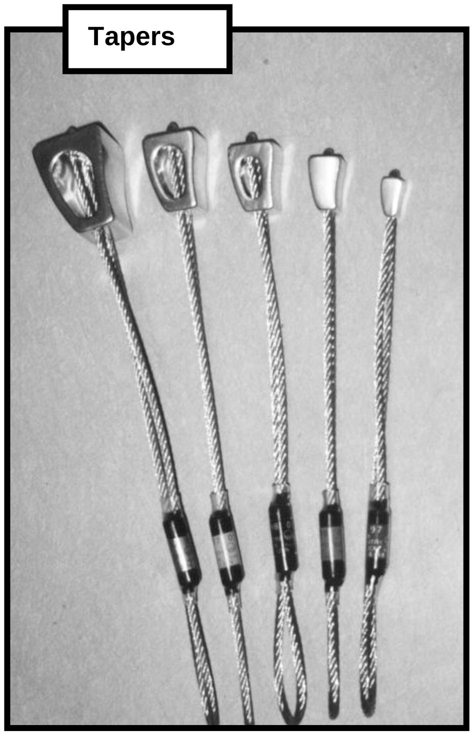
As a rule of thumb, I will always advocate the use of no less than a series of three (3) artificial anchors, brought together using a load sharing system for the purpose of supporting a system load.

Warning: This is an advanced rope rigging skill. Before attempting to use any form of artificial anchor, instruction in their use must be obtained through a certified school of rope rescue!

Hexentrics

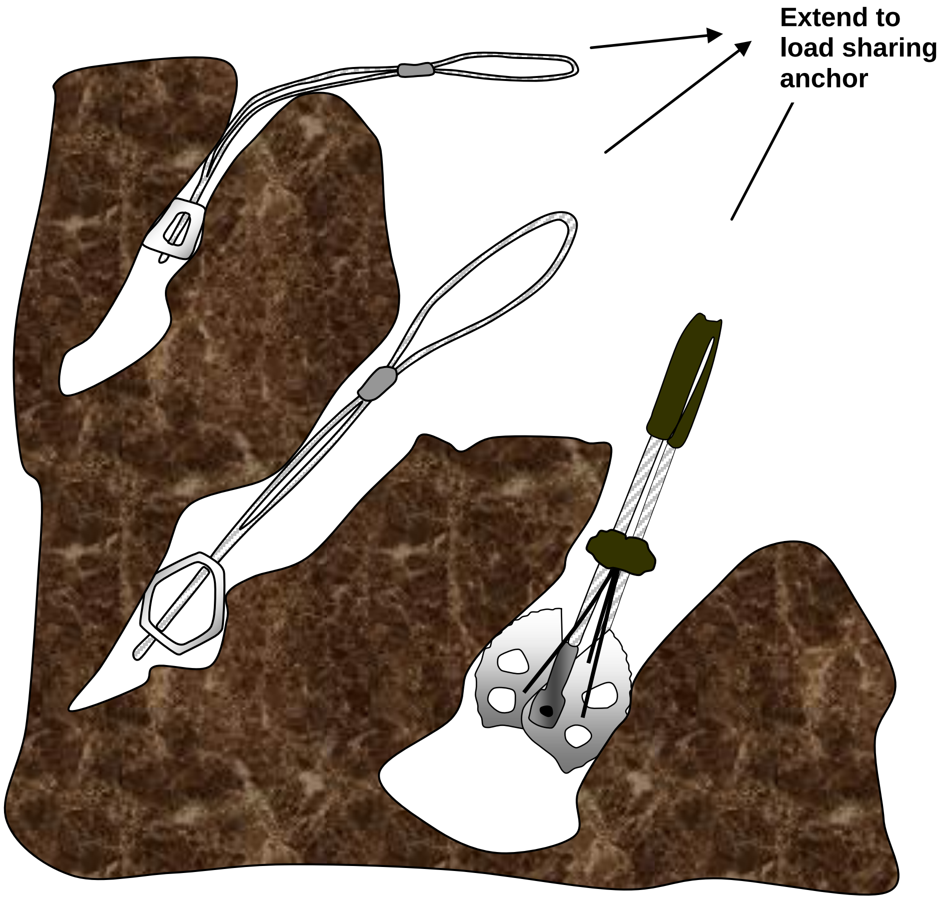


Tapers



Cleaning Tool

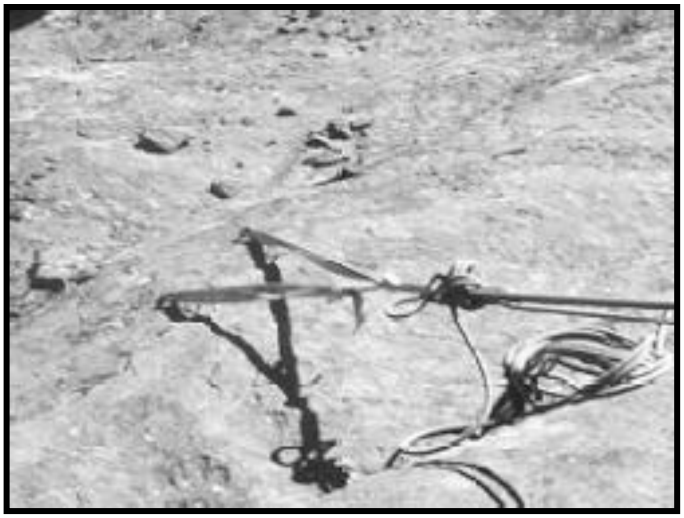
Artificial Anchors
(Rock Pro)



Rock Pro is a wonderful tool for anchor construction. It is very important to match the correct size pro with the depth and width of the crack. In addition, soft rock, such as sandstone must go much deeper than a harder rock like granite.

Again, this is an advanced skill that must be learned through years of practice under that guidance of a qualified instructor.

Bolts



Bolts, on very rare occasions may be used. The main advantage to bolting is it makes for incredibly strong anchors (when properly done) where no natural anchors exist. Unfortunately, it comes at a very high price.

There are at least three main disadvantages to using bolts during a rescue:

1. It is very equipment intensive, especially in the backcountry.
2. Using bolts is an advanced skill that may become deadly if it is performed by an untrained rescuer.
3. It scars the landscape, making the practice of this skill somewhat difficult.

Bolts and hangers used as a single point bomb proof anchor, should have at least a 9000 pound shear rating, typically a 3 ½ "x ¾ " bolt drilled to 3" in depth. All hangers should be made of stainless steel, and must be secured with a nut.

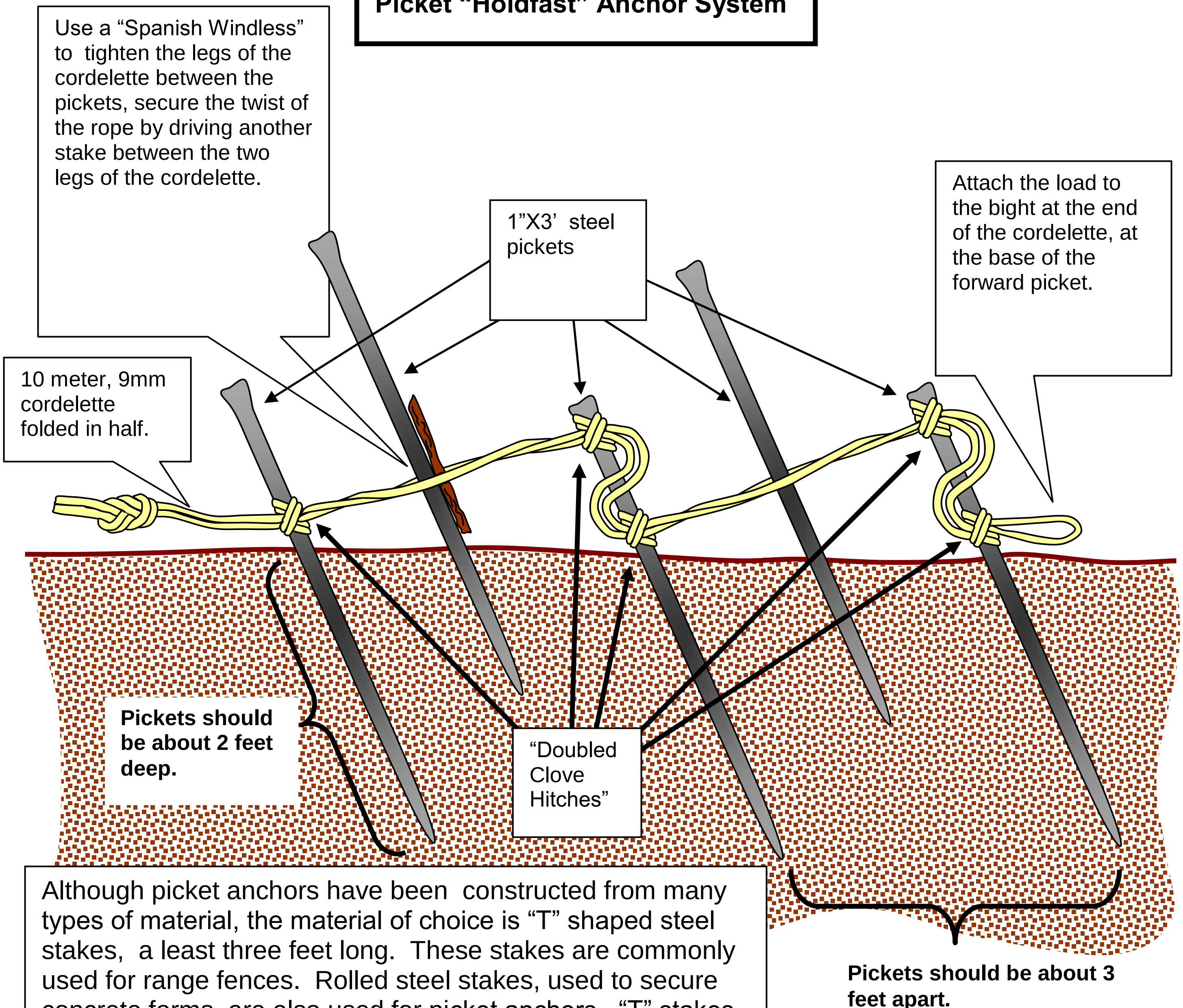
Typically, bolts used for multi-point anchors should be grouped in sets of at least two, using a load sharing system, extending each anchor to single point.

We would advice not using any bolt less than 3/8 inch in diameter for multi-point anchors. All bolts, nuts and hangers must be installed in accordance to the manufactures recommendations.

There are a number of quality manufactures of bolts suitable for rope rescue, to name a few: Star, Phillips, Hilti, and Wej-it.

Warning: The use of bolts is an advanced rigging skill, do not attempt to install bolts without proper instruction from a certified school of rope rescue.

Picket "Holdfast" Anchor System

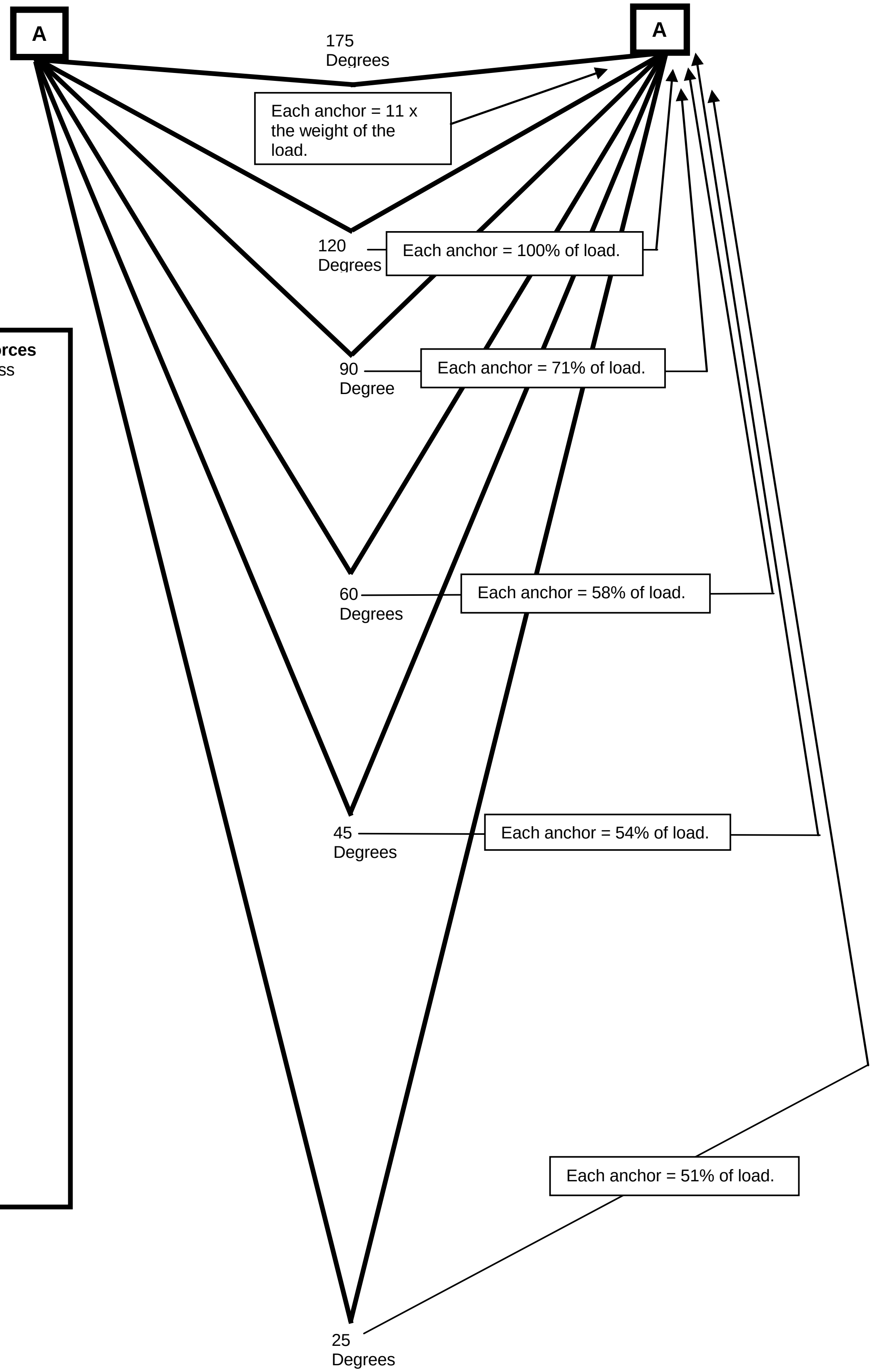


Although picket anchors have been constructed from many types of material, the material of choice is "T" shaped steel stakes, a least three feet long. These stakes are commonly used for range fences. Rolled steel stakes, used to secure concrete forms, are also used for picket anchors. "T" stakes work better in loose soil or sand, preventing the "plowing" of the ground, while rolled steel may be better suited for hard rocky ground because of better penetrating qualities.

The pickets should be driven into the ground about two feet, slanted approximately 15^{o}, and about 3 feet apart.

Use a 10 meter, 9mm cordelette to tighten and secure the top of the first picket to the bottom of the second picket, and the top of the second picket to the bottom of the third. Use "Doubled Clove Hitches" for the connection points of the cordelette to the pickets.

Note:
For extreme loads that could exceed 450 pounds, two 9mm cordelettes, or doubled 1" webbing loops should be employed to secure the picket and create the last anchor attachment loop.



Anchor Vector Forces

Degree	% of Mass
0	.5
5	.5005
10	.502
15	.504
20	.508
25	.512
30	.518
35	.524
40	.532
45	.541
50	.552
55	.564
60	.577
65	.593
70	.611
75	.631
80	.653
85	.678
90	.707
95	.74
100	.778
105	.821
110	.871
115	.931
120	1.
125	1.08
130	1.18
135	1.31
140	1.46
145	1.66
150	1.93
155	2.31
160	2.87
165	3.82
170	5.75
175	11.36
180	56.

Chapter 6, Belay Systems

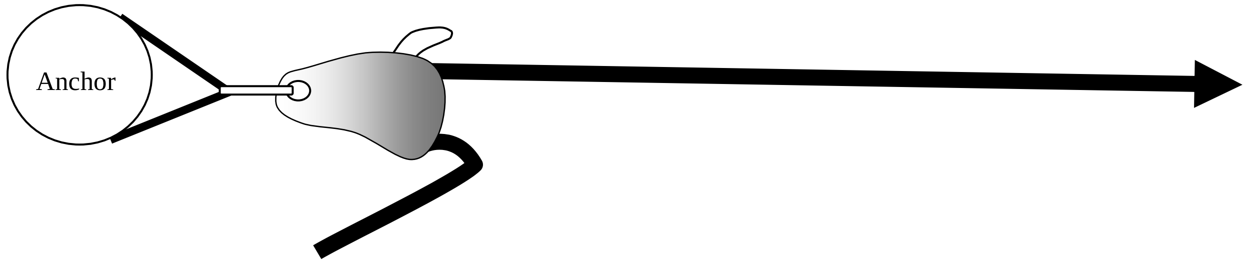
In rescue work, belaying is a process of protecting and arresting an accidental fall due to human error, or system failure. It involves the utilization of a backup lifeline from the rescue package to a belay device, which is securely attached to a secondary anchor. Belaying is an integral part of the rescue system, and it is done any time there is “exposure” to falling.

The belayer needs to be attentive to the operation of the working line. It is the responsibility of the belayer to control the belay line in such a manner that it is not carrying the rescue load, but at the same time, keeping slack in the belay system to a minimum. A quality belay system includes sound rigging and proper belay technique that quickly allows the belayer to pay rope in or out without hesitation.

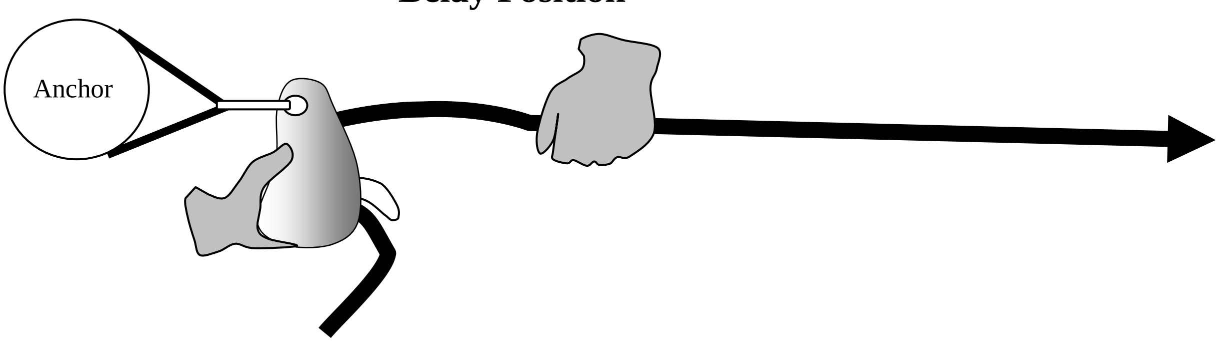
Belaying with the Petzl ID

The Petzl ID provides an excellent option for system belays, especially for industrial applications. The ID truly passes all fail safe testing criteria. Rig the ID in accordance to the Petzl User Manual, simply hold the ID perpendicular to the belay anchor and allow the rope to pull through. Manage the slack by pulling the rope back towards the ID. During the use of hauling systems; simply pull the rope through the ID. During the operation of belaying with the ID, the handle stays in the natural position. When leaving the belay station, rotate the handle to the locked position.

Loaded Position



Belay Position



Tandem Prusik Belay (TPB)

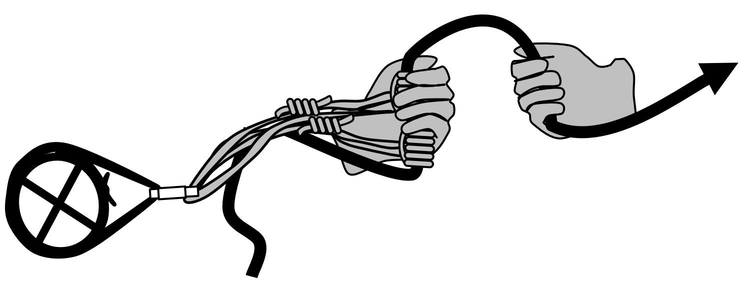
The TPB is often considered a dead man belay that affords minimal damage to the system and will always arrest the load during a free fall. Several recent tests have presented multiple red flags that seem to revolve around the user's skill in understanding and operating this type of rigging and knot craft. The TPB system will probably be around for many more years and is a valuable tool for minimalistic rigging as might be used with mountain rescue groups. This is a proven system, but substantial practice and advance understanding of prusiks, rigging physics is mandatory.

The tandem prusiks (triple wrapped) should be cut in length of 65" for the long loop and 57" for the short loop, the loops are made by tying a *Double Overhand Bend*. The manufactured Long/short stitched prusik loops provide the best option.

Tandem Prusik Belay

Proper Technique for the Tandem Prusik Belay, *the Bubble Turn.*

The tandem prusiks should be tight enough around the host rope that the belayer can hear the belay rope going through the prusiks.



The tandem prusiks must be held back from accidental locking and at the same time, quickly lock if a system failure occurs. The best way to accomplish this is through using the *Bubble Turn* technique. Note that the hand manning the prusiks is bending the prusiks perpendicular to the ground; this will facilitate a much quicker grab of the prusiks when needed. The other hand will feel the weight of the load; as the bubble (the length of rope between the hands) gets smaller, the belay simply pulls a section of the rope through the prusiks (the hand movement should be approximately shoulder width) and creates a new bubble. Also note that the thumbs do not grab the rope; we want the system to be snapped from the belayer's hands if a failure happens.

Note: The belay line must have the least amount of slack as possible for the safest operation.

Chapter 7, Mainline Operations,

When building a Mainline system, consider the possibility of the need to convert from a lowering system to a raising system. There are numerous hidden factors that have caught many teams by surprise. By predicting these factors and pre-planning the Mainline, life becomes much easier and safer when the time comes to convert to the raising system.

Typically, lowering systems are safer then raising systems because we are cooperating with gravity. As soon as we go to a raising system gravity becomes our prime enemy, and gravity's most powerful accomplice is friction. What we are talking about mostly is the friction coefficient or Mainline contact with the surface between the Mainline anchor and the rescue package. Yes, friction is working in our favor during the lowering process, and if we are going down only, then ground friction isn't that big of a deal (although we still keep a sharp eye out for rope abrasion, and damage), but when it is known that a raising system is going to be employed, we must mitigate rope contact with the surface before the lowering system is put into action. This is best accomplished by the use of a high directional. (See Ch. 8, High Directionals)

The Ideal Load Weight (ILW) is the weight of the load during a static state; the Practical Load Weight (PLW) is the actual weight of the load plus the effects of the friction coefficient. Unfortunately, this fact is many times overlooked by many teams. During a lowering with approximately 20 feet of rope contact with the surface, the PLW of a 450 pound two person load may be only 150 pounds. During a raising with the same 20 feet of rope drag, the PLW will skyrocket to about 1100 pounds!

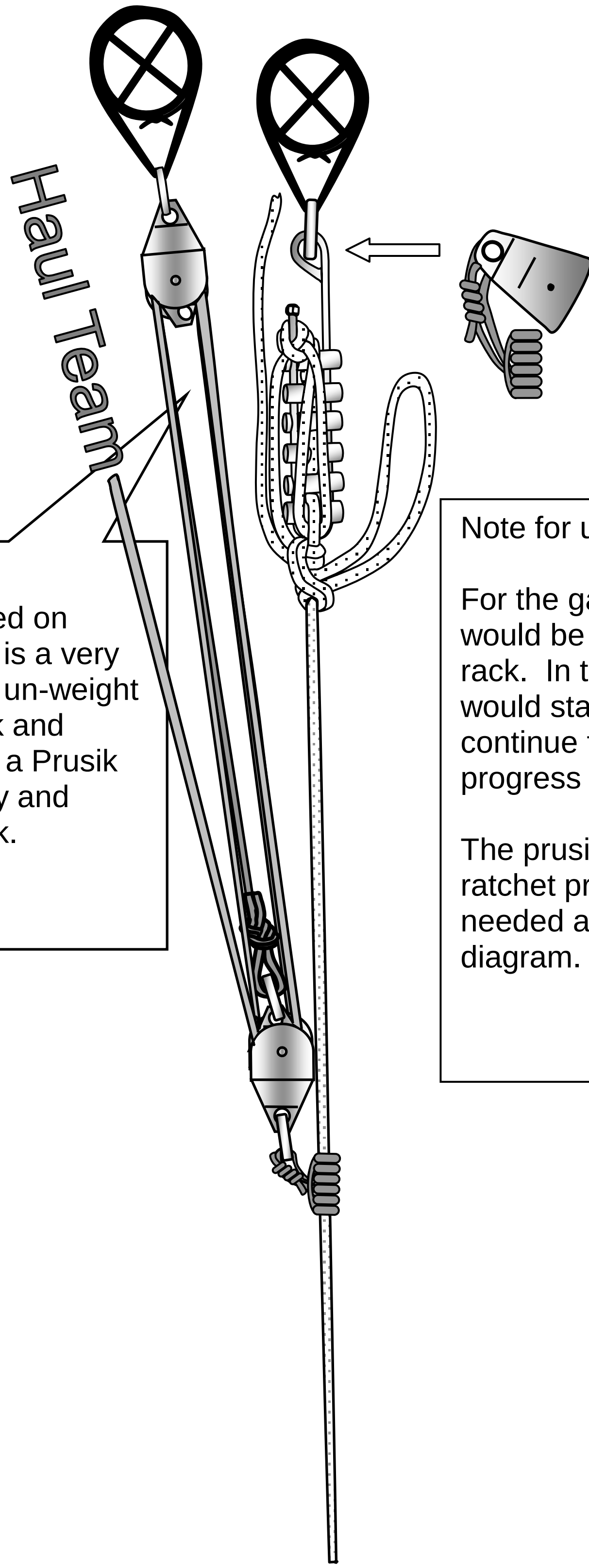
What does this mean to our anchor selection? With the use of a high directional the unwanted friction is all but eliminated. Without the use of a high directional, our anchor system is very susceptible to this hidden weight and possibly prone to failure. Control of all the many aspects of friction during a rope rescue operation is a must.

Equipment for Lowering Systems

For the most part, the "6" bar Brake Rack has been the standard for a friction lowering device. The Brake Rack offers maximum control, and with a little practice it can become very easy to operate. There are however, new products of the horizon that are much more user friendly. One that is on the market now is the BMS (Bassett Metal Studios) Micro-rack. I have used the BMS Micro-rack extensively, and have found it to perform exceedingly well.

Many teams automatically include a rigging plate in the construction of their Mainline system. All thought at times a rigging plate is useful in making other adjunct attachments to the system, we do not consider it a mandatory part of mainline construction. When a rigging plate is needed, choose the smallest one available.

Converting From a Lowering to a Raise with a Ganged Pulley System



Using a ganged on pulley system is a very simple way to un-weight the brake rack and replace it with a Prusik Minding Pulley and Ratchet Prusik.

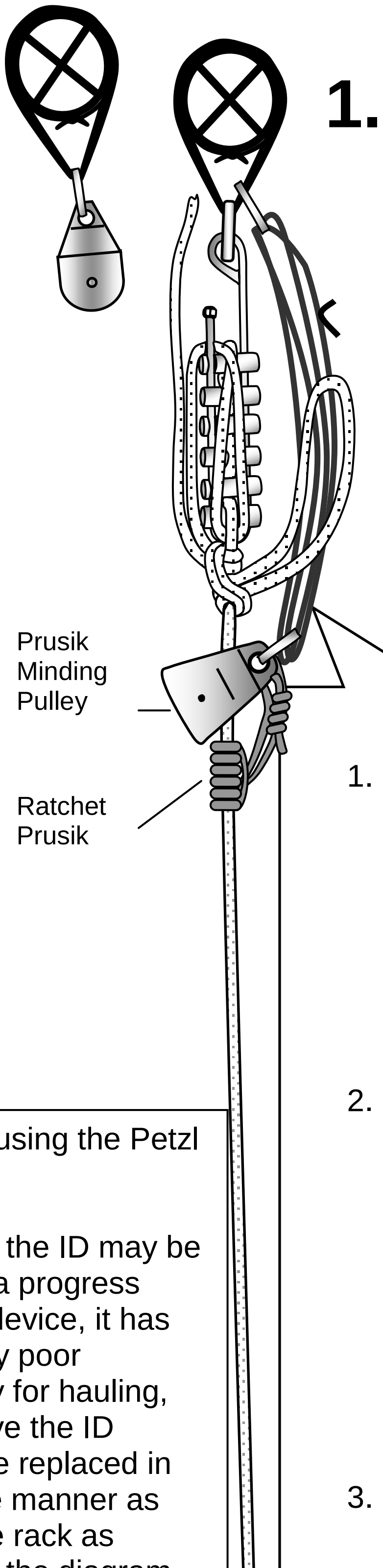
Note for using the Petzl ID

For the ganged system the ID would be in place of the brake rack. In this application, the ID would stay in the system and continue to be used as the progress capture device.

The prusik minding pulley and ratchet prusik would not be needed as shown in this diagram.

Converting From a Lowering to a Raise with an Intrical Pulley System
(Belay Line has been omitted for clarity)

1.



1. Use a doubled webbing loop long enough to extend the prusik minding pulley and ratchet prusik in front of the brake rack .

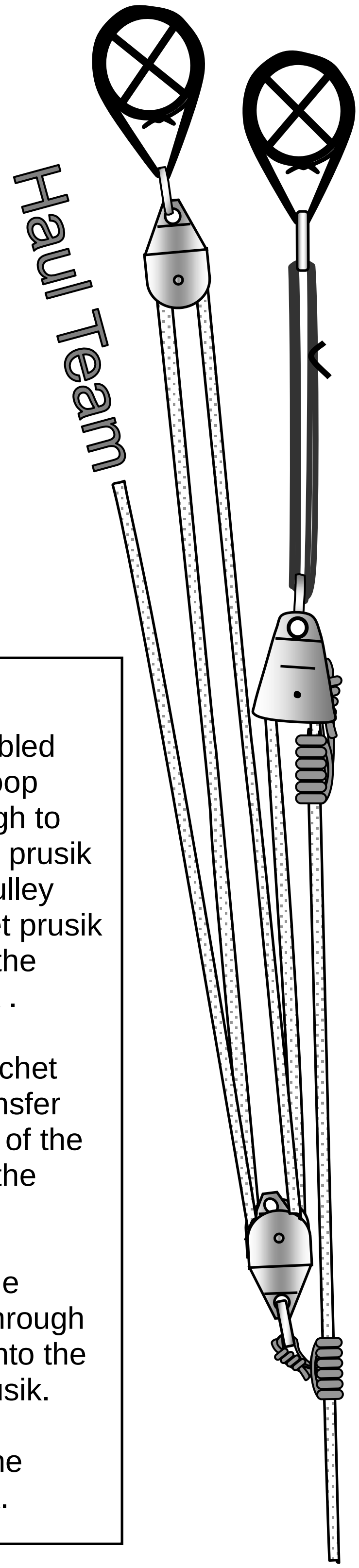
2. Set the ratchet prusik, transfer the weight of the load from the rack to the ratchet by slacking the mainline through the rack onto the ratchet prusik.

3. Remove the brake rack.

Note for using the Petzl ID

Although the ID may be used as a progress capture device, it has extremely poor efficiency for hauling, we believe the ID should be replaced in the same manner as the brake rack as shown in the diagram.

2.



Once the load is transferred to the ratchet, the rest of the pulley system may be constructed.

To transfer back to a lowering, simply pull enough slack through the pulley system to rig the brake rack behind the ratchet.

Use the remaining pulley system to release the ratchet an lower the load back onto the rack.

Maintain tension on the rack, or tie it off, and disassemble the pulley system.

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Pre-plan the Working Line

All too often, teams rig their haul system with the progress capture device (the ratchet) at a directional anchor located in front of the mechanical advantage system. This ratchet position is most often due to the lack of pre-planning the layout of the working/haul line system.

Usually the rigger will build the braking system for lowering at the anchor most inline with the fall line. Typically, this anchor is too close to the edge and offers a very small throw for the soon to become haul system. To over come this problem the team will then look for another anchor that will provide a longer throw and hauling field beyond, or to the side of the first anchor.

One problem leads to another. The working line, now in need of a hot change-over, (going from a lowering to a raise under tension) has only one place the brake system (lowering) can be replaced with a ratchet (raising). This is at the original anchor, the one closest to the edge, the one that is now a forward directional for the haul system.

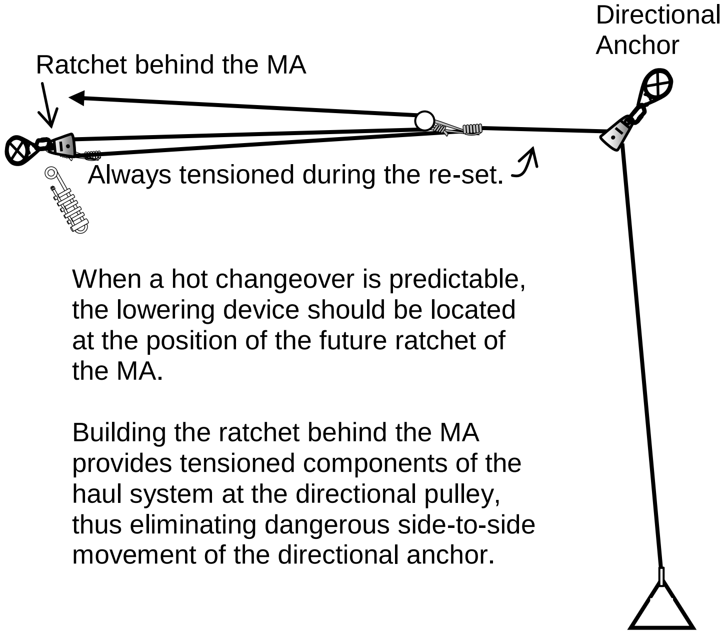
There are some inherent problems with a ratchet that is in front of the MA. During the re-set phase of the haul, the rope behind the haul rope grab device is always slack, making for sloppy re-sets, but even more problematic, is the ebb and flow, back and forth movement of the directional anchor that occurs between re-sets and even at every tug of the rope. At best, this type of inefficient system mandates a back-tie that opposes the haul team.

As a result of this ebb and flow movement, the continual change in the force vector of the directional anchor gives us great concern to the integrity of the anchor. Keep in mind when looking at the drawings below, the static weight of the load at the directional anchor (non-moving, with equal tension on both sides of the directional pulley) is approximately 141% greater after the conversion to a raising system than it was during the lowering. The anchor stress will always be substantially greater during a haul than during a lowering. When choosing an anchor for a lowering system, we must build it strong enough to withstand the forces generated by the raising system that we will be going to later.

What is the friction profile of the edge? Are we making a 90-degree turn over sandstone or granite, or are we utilizing a high directional? During a raise, a 90-degree turn over a rock surface will ad over 3x the weight of the load at the edge. Using the force vector formula on page 114, one can quickly see the potential for a catastrophic failure of an underestimated directional anchor. The problem is magnified when the
ratchet is put at the forward position, this constant change of low tension to high tension and back again is what has been the down fall of many anchors.

The solution to this problem is very simple, pre-plan the best location for the future haul system and ratchet and put the braking device for the lowering at that position from the start.

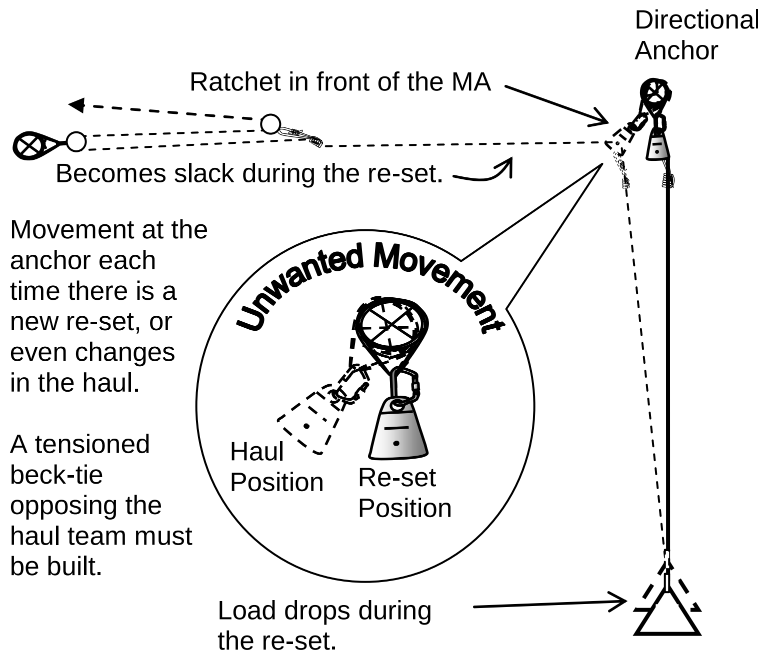
Fig. 1 ***YES***



When a hot changeover is predictable, the lowering device should be located at the position of the future ratchet of the MA.

Building the ratchet behind the MA provides tensioned components of the haul system at the directional pulley, thus eliminating dangerous side-to-side movement of the directional anchor.

Fig. 2 ***NO***



Movement at the anchor each time there is a new re-set, or even changes in the haul.

A tensioned beck-tie opposing the haul team must be built.

Mechanical Advantage with Pulley Systems

There are three categories of mechanical advantages using pulleys; Simple, Compound, and complex. A Simple MA consists of a pulley system that has a single haul connection between the load and the haul team. A Compound MA is a simple mechanical advantage system pulling on the haul line of another simple mechanical advantage. Multiplying the two systems will give the total advantage.
Here are five rules that can be used to determine simple and compound mechanical advantage systems.

1. If the pulley closest to the haulers is on the anchor, the pulley is only considered a change of direction (cd). Same rule applies to ANY pulley system.
2. If the rope used in the pulley system is tied to the anchor, the ideal mechanical advantage (IMA) will be EVEN (i.e., 2:1, 4:1. 6:1, etc.)
3. If the rope used in the pulley system is tied to the load, the ideal mechanical advantage (IMA) will be ODD (i.e., 1:1, 3:1. 5:1, etc.)
4. To determine the IMA of a simple pulley system, count the ropes between the anchor and the load. Do not count the ropes between two anchors.
5. A simple MA pulling on the haul line of another simple MA is called a compound MA system.

A Complex MA system is neither simple or compound, and the above rules will not work in determining the system. The only way in determining the mechanical advantage of a complex MA system is by calculating the "tension units". *(See "Critical Thinking On Mechanical Advantage Systems" at the end of this section.)* The combinations of pulleys that can be incorporated in an MA system are infinite. With this in mind, how many pulleys are needed, and what are the characteristics of a quality haul system?

In general, the ideal mechanical advantage (IMA) is the ratio between the distance the load moves and distances the haul team moves. In a 2:1 system the load will move 1' to every 2' of haul. However, this does not mean that lifting the load is twice as easy. The practical mechanical advantage (PMA), or simply put, the efficiency of the system, is the actual physical advantage the haul team ends up with. In short, based on the size of the haul team, try to build the MA system as small as possible. More pulleys create more friction, resulting in efficiency loss.

Consider the hauling field; that is to say, configure the MA system in a way that maximizes that amount of ground area the haul team can operate. This will also minimize the number of re-sets of the haul system. Build the MA system clean. Avoid crossed or twisted lines, as this will add unwanted friction in the system.

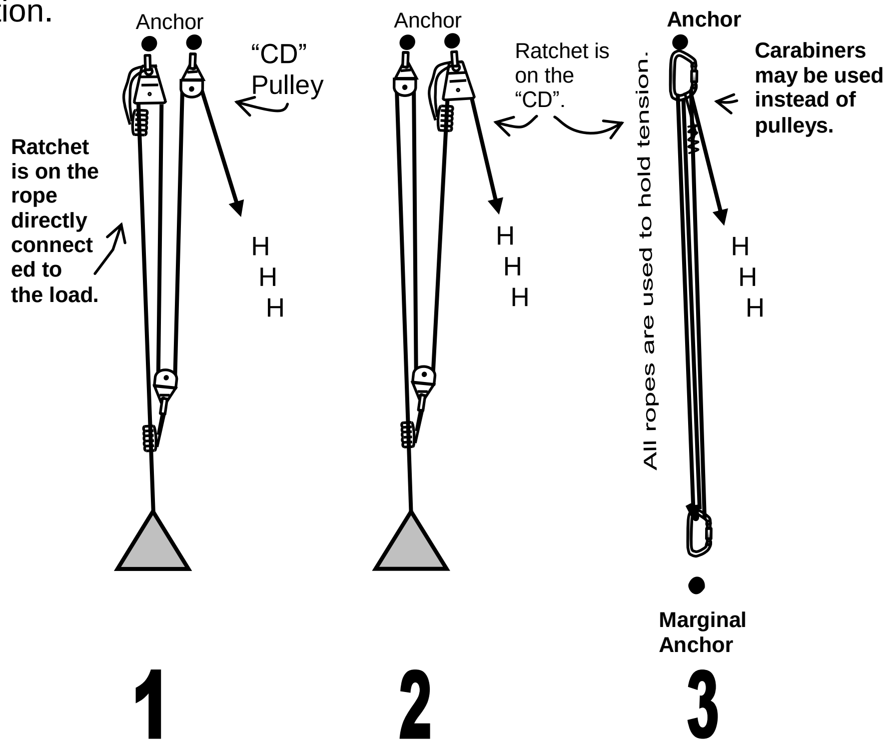
When the haul prusik slips this is an indication that something is not right. Do not add an additional prusik, correct the problem. A slipping haul prusik as like having a pressure relief device in the system, the haul prusik typically slips between 800 and 1200 pounds. With the exception of tandem haul prusiks on a tensioning system for a "highline" operation, putting tandem haul prusiks in the MA is like replacing a 15-amp fuse with a 30-amp fuse, something could very well fail.

A "ganged on" MA system is separate from the main line. An "integral" MA system is built with the same rope as the main line, and runs continuous from the load to the haul team. Each way offers advantages; the "integral" system is less equipment intensive. "Ganged on" systems can be pre-rigged, and moved into place speeding the change over from a lowering system to a raising system. A ”piggyback” MA is a compound system that consist of two or more identical simple mechanical advantages, i.e., a 2:1 pulling on a 2:1 equals a compound “piggyback” 4:1.

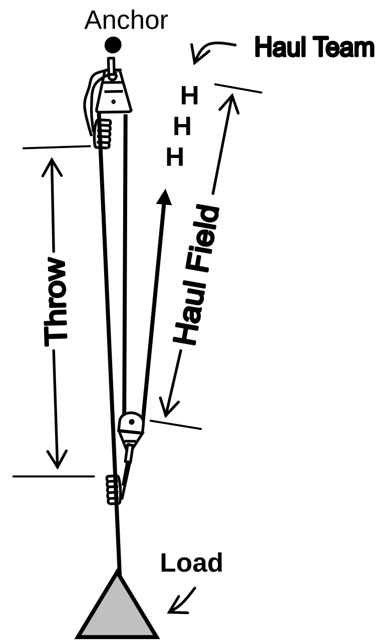
Pulley Systems for Hauling, Lowering, and Holding

Rope rescue requires rigging skills to either move things or hold things in place. As simple as this sounds, a complete working knowledge of pulley systems and mechanical advantage is a must. Pulley systems used for lifting a load horizontally are somewhat different than a pulley system or mechanical advantage used to back-tie a tree or guy a high directional. In addition to hauling and holding, a third type of pulley system is used for rapid changes from a hauling system to a lowering system. The difference of all these examples is the position of the ratchet (progress capture device).

1. **Hauling** pulley systems are designed to hold the load during resets of a hauling operation. The ratchet is on the leg of rope directly connected to the load.
2. **Hauling, Lowering and Rapid Response** pulley systems may be used up or down very quickly The ratchet is on the change of direction.
3. **Back-tie** pulley systems are designed to maintain tension between two anchor points (May use only carabiners as pulleys). The ratchet is on the change of direction.



Other Considerations



- Rope and Equipment ---How much rope, pulleys, carabiners and other needed equipment is available?
- Size of the Load (output) ---What and how much weight is required to lift? Is it a single person, or a rescue or extreme rescue load?
- Number of Haulers (input) ---What are the man power resources available for hauling?
- Work Area---What is the size of the work area for the team to safely operate?
- Throw ---What is the distance the MA system can operate before a reset?
- Incline of the Hauling Field---Is the hauling field level? Downhill hauls are much easier than uphill.
- Adaptability---Can you easily change to a larger or smaller mechanical advantage?
- Lowering ---Can the pulley system be employed as a lowering system?

Clarification of MA Terms

Integral Versus Ganged On; Plain and simple, if its built with the one rope that is connected to the load it is a integral system, this may be a simple, compound, or a complex system. A ganged system is an MA which is built with a separate rope that is attached to the working rope.

Ganged On Versus Piggyback; A piggyback system is a compound MA that is made up of two or more ***identical*** simple MA's. i.e. a compound 4:1 (2:1)(2:1). A Ganged MA system is attached by a haul grab to a second main rope for the purpose of lifting or lowering a load.

Change of Direction Versus Directional; A change of direction is a pulley on the anchor closest to the haulers, notated (cd). A cd adds no mechanical advantage to the system. A directional is a pulley or pulleys between the pulley system and the load to be raised, notated (d) or (1:1)

Throw Versus the Haul Field; The throw is the available distance between maximum pulley system extension and two-block (Note: Simple pulley systems have only one throw. Compound pulley systems have a minimum of two throws) The haul field is the available distance a hauler or haulers can run out or the space that they have to stand and pull.

Simple Pulley Systems

Simple pulley systems must be considered one of the primary tools of rope rescue work. Some of the advantages are; they are easy to remember and perform. They have long throws and are easily modified if more advantage is needed. The disadvantages are, they typically have more friction, use more rope, and require more equipment in larger MAs.

Pulley systems are the backbone of most technical rescues.

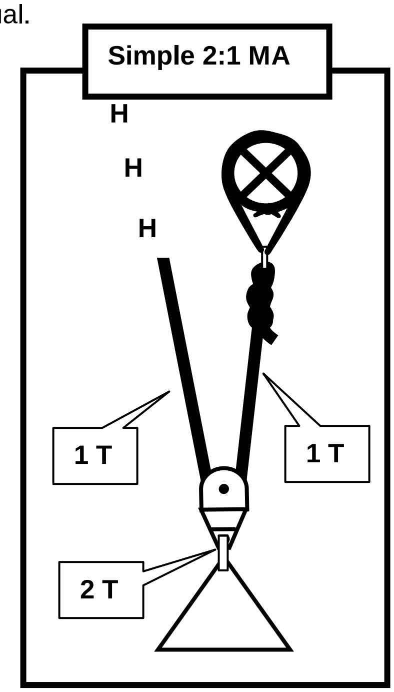
Critical Thinking on Mechanical Advantages

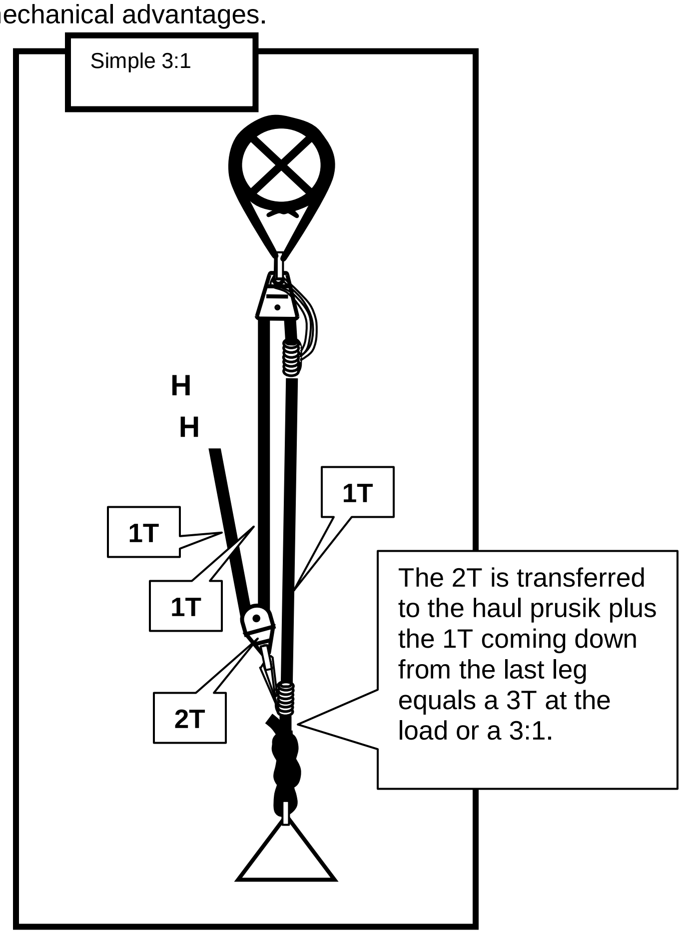
Understanding how to calculate the ideal mechanical advantage (IMA), and the practical mechanical advantage (PMA) can be extremely useful in developing skills that will assist the technician in building mechanical advantages that are the most efficient for the job at hand. This is done by determining the amount of tension on each pulley in the system.

All operational pulleys have two legs of rope, one leg going in, and one leg coming out. The tension or force these two legs apply to the pulley will *always* be equal. This is most readily seen in the simplest of mechanical advantages, the 2:1. One leg is attached to the anchor, it runs in a pulley connected to the load, and the second leg comes out the pulley to the haul team.

As we said earlier, both legs of the same pulley are equal, so if we assign 1 tension unit to the first leg of the pulley than the other leg must also be equal to 1 tension unit.

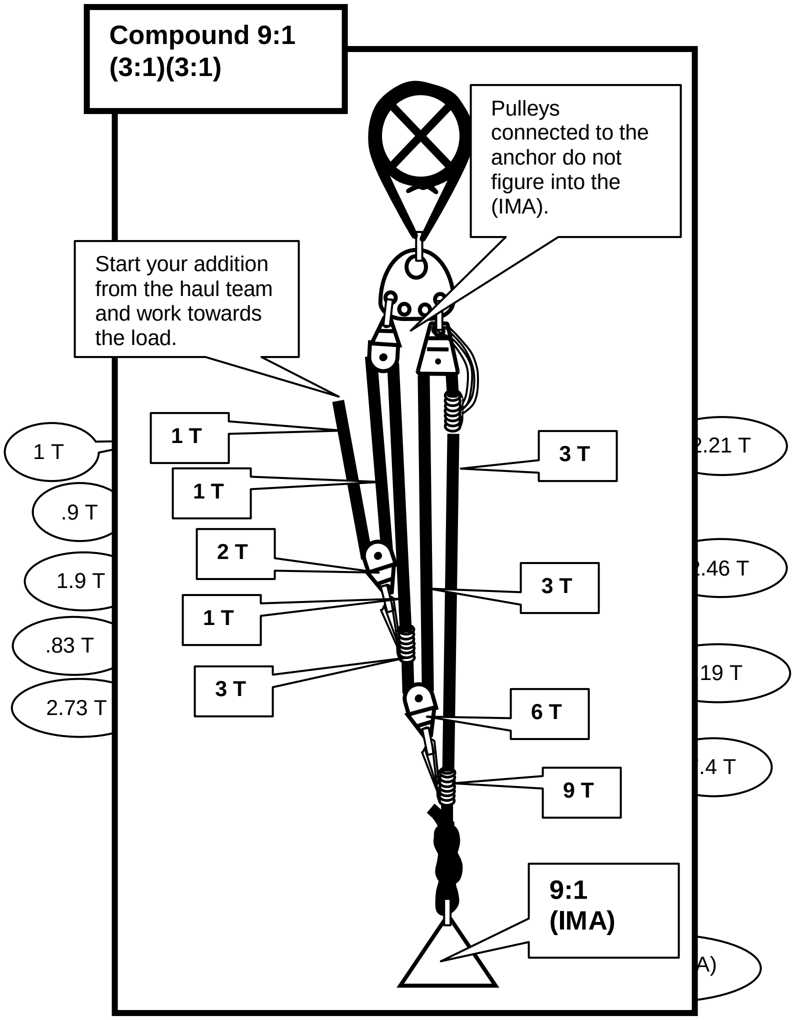
These two legs add up to equal 2 tension units at the pulley. There for, when the haul team applies 1 tension unit of pull, they benefit from 2 tension units of lift on the load. This is the *"D N A"* of mechanical advantages.





A few simple tips to remember when calculating the tension units of an MA is:

- Start adding the tension units with the leg closest to the haul team.
- Pulleys that are connected directly to the anchor do not contribute to the MA.
- When the tension units of a pulley that is pulling on the haul leg of another MA system (compound and complex systems) those tension units are transferred to that haul leg.



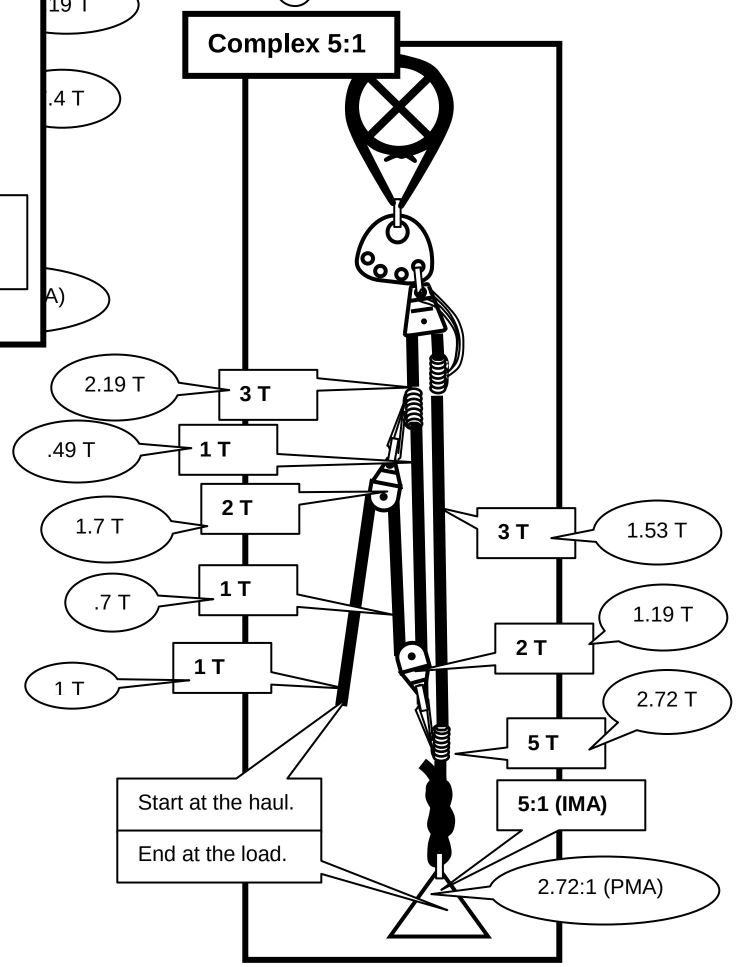
Practical Mechanical Advantages (PMA)

The (IMA) is based on 100% efficiency, but because of friction and inefficiency of the pulleys (most ball bearing pulleys are about 90% efficient, and bushing pulleys are about 70% efficient) it is important to understand the (PMA) of the system.

Generally speaking, the more pulleys in the system the less efficient it will be.

Take ball bearing pulleys, 90% efficient, each time the rope passes through the pulley, it looses 10% of its efficiency. This efficiency loss is multiplied each time the rope passes through another pulley.

Note the 9:1 MA to the left, the round callouts denote the (PMA) figures.

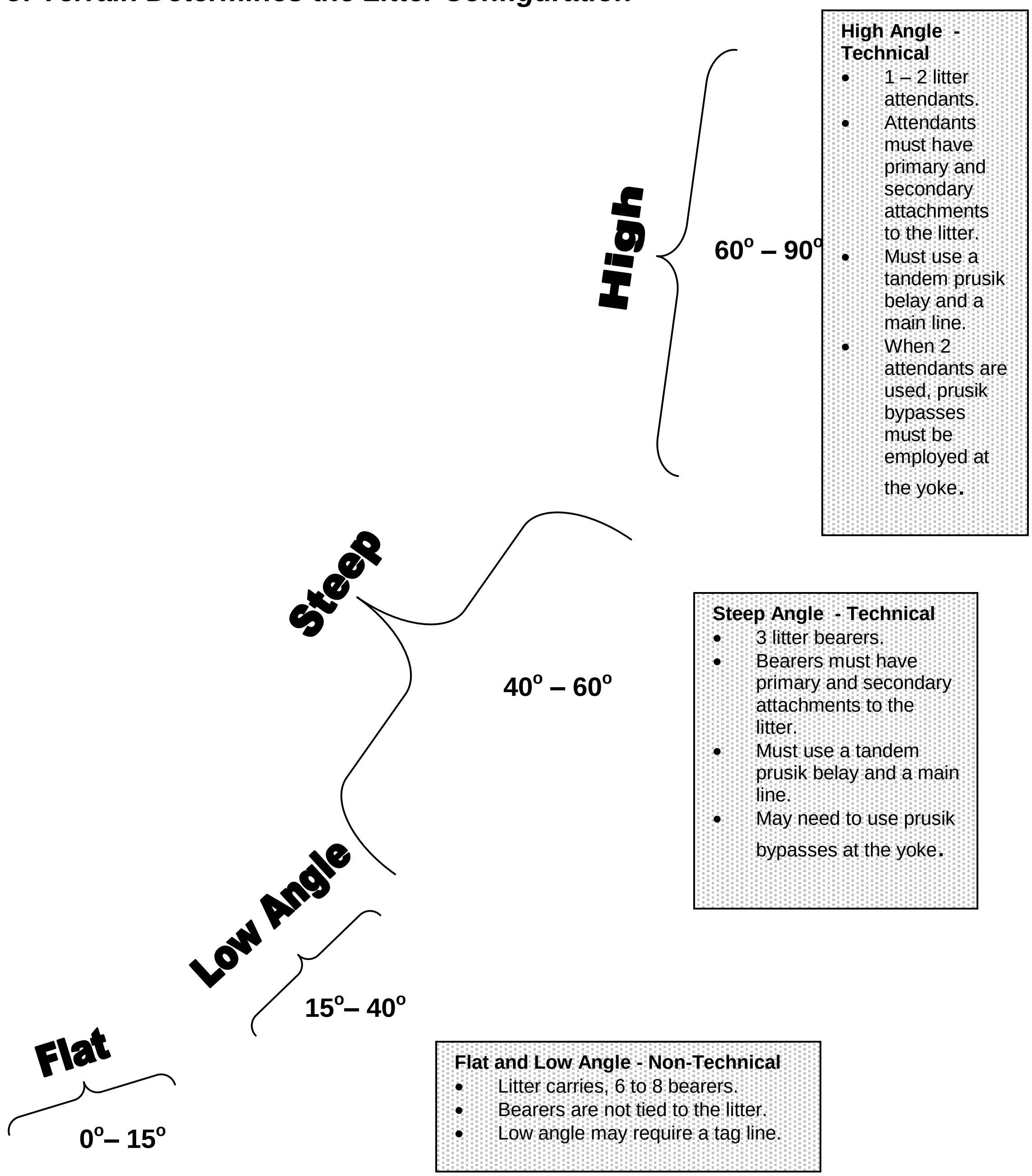


Note the complex 5:1 to the right. In this case we will calculate the efficiency loss of bushing pulleys. (70% efficient) The Ideal Mechanical Advantage (IMA) is denoted by the square callouts, and the Practical Mechanical Advantage (PMA) by the round callouts.

Chapter 8, Litter Configurations

As with all aspects of rope rescue, depending of which school you adhere to, there are many ways to rig the litter package. In an attempt to stay consistent with the underlying theme of this book*, keep it simple and applicable*, we will focus on one type of connection for the litter, namely, the use of the *Doubled Long Tail Bowline.* This will be the connecting loop, or *yoke,* for high angle vertical configurations as well as steep angle horizontal configurations.

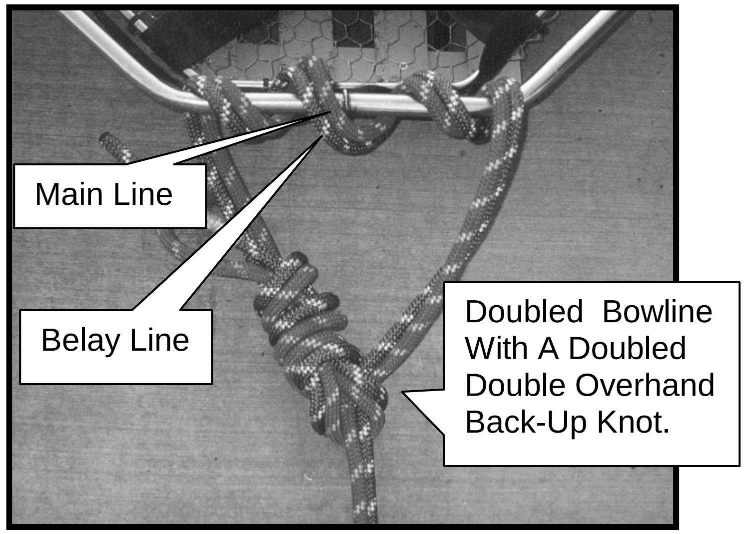
The Type of Terrain Determines the Litter Configuration



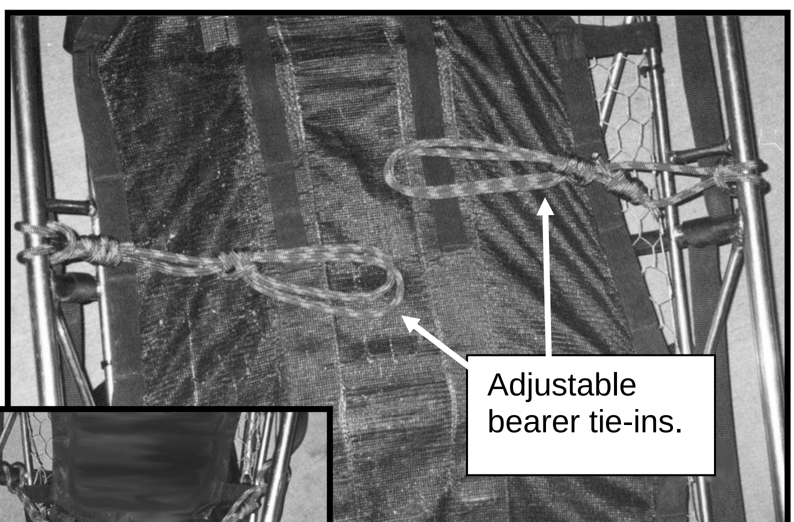
Steep Angle Litter Configuration Technical, Low Exposure,

Steep angle extrications that are of a lesser exposure may be rigged according to the photo to the right. This is the time when you know you must use, at least, a tag line but the question arises, is a tag line alone secure enough to safely do the job?

If there is any doubt about the use of a tag line, go with a steep angle operation.

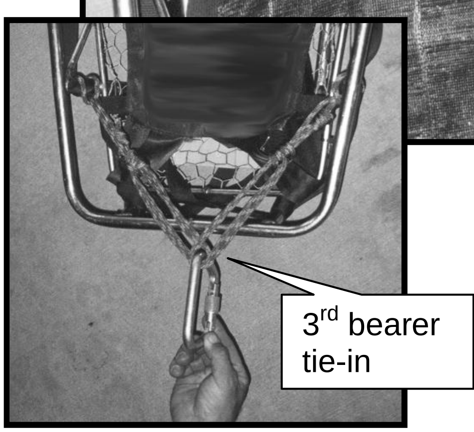


The doubled bowline is the best knot at the yoke for a low exposure steep angle operation. It is easy to tie and inspect. The main line and the belay line are connected, via the doubled bowline, to the bottom litter struts, and candy stripped to the litter rails. The resulting loop should form approximately, an equal-sided triangle that captures the litter at its strongest point.



Adjustable bearer tie-ins: Constructed from approximately 77" of 8mm accessory cord. A loop is formed by tying a double overhand bend. The adjustable loop is formed by a 3-2 prusik hitch on itself. (3 wraps on the top, and 2 wraps on the bottom) The tie-in is attached to the top rail of the litter with a girth hitch.

When using 4 bearers, two are attached towards the top, and two are attached near the bottom.



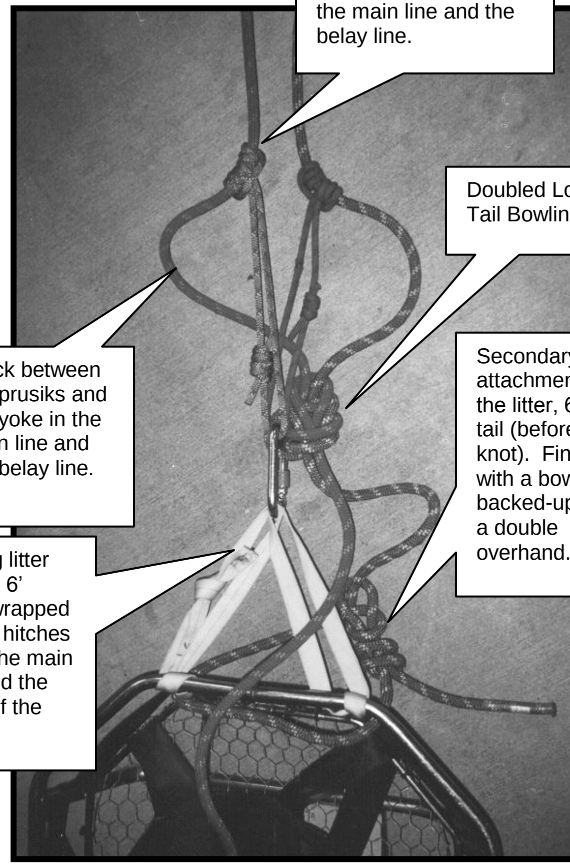
With a 3 bearer configuration, 2 bearers are towards the top of the litter, and the 3rd bearer will tie-in at the very back of the litter using two adjustable tie-ins, forming a "V" off of the back two struts of the litter. In all steep angle configurations, the bearers will connect the tie-ins to the waist "D" ring of their harness.

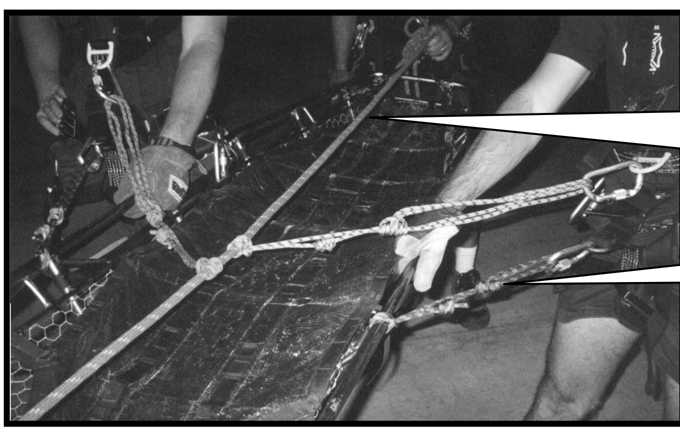
Steep Angle Litter Configuration Technical, Greater Exposures

Any time a steep angle operation approaches “high angle” terrain (approximately $\pm 60^{o}$), the potential for system failure becomes a very real concern. This is due to excessive forces on the system generated by the tremendous weight of the load, typically 3 litter bearers and the victim. This is one of the largest rescue packages a team may ever encounter.

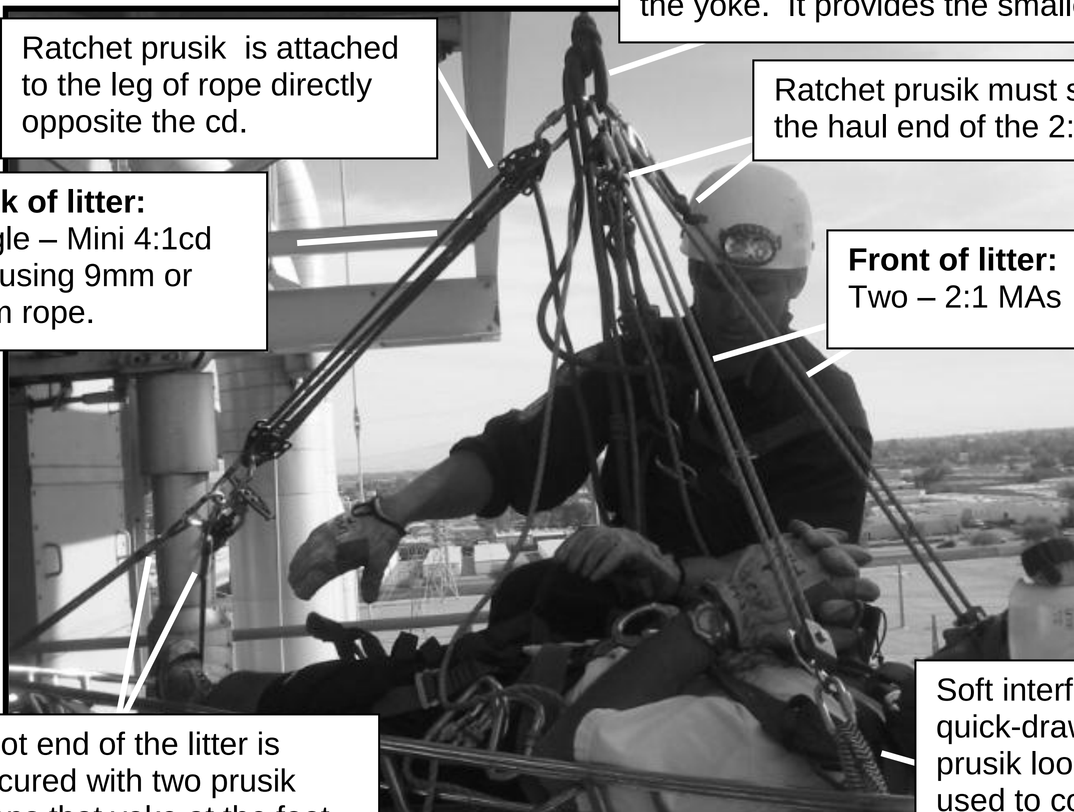
When performing a high exposure steep angle evacuation these considerations should be followed:

- Employ 8mm prusik by-passes on the main line and the belay line at the yoke.
- Secondary attachments for the litter and the litter bearers.
- Do not use more than 3 litter bearers.





High Angle Litter Configuration Using the RescueRig Litter System



The Double Long Tail Bowline is used for the yoke. It provides the smallest gain.

Ratchet prusik is attached to the leg of rope directly opposite the cd.

Ratchet prusik must secure the haul end of the 2:1

Back of litter:
Single – Mini 4:1cd MA using 9mm or 8mm rope.

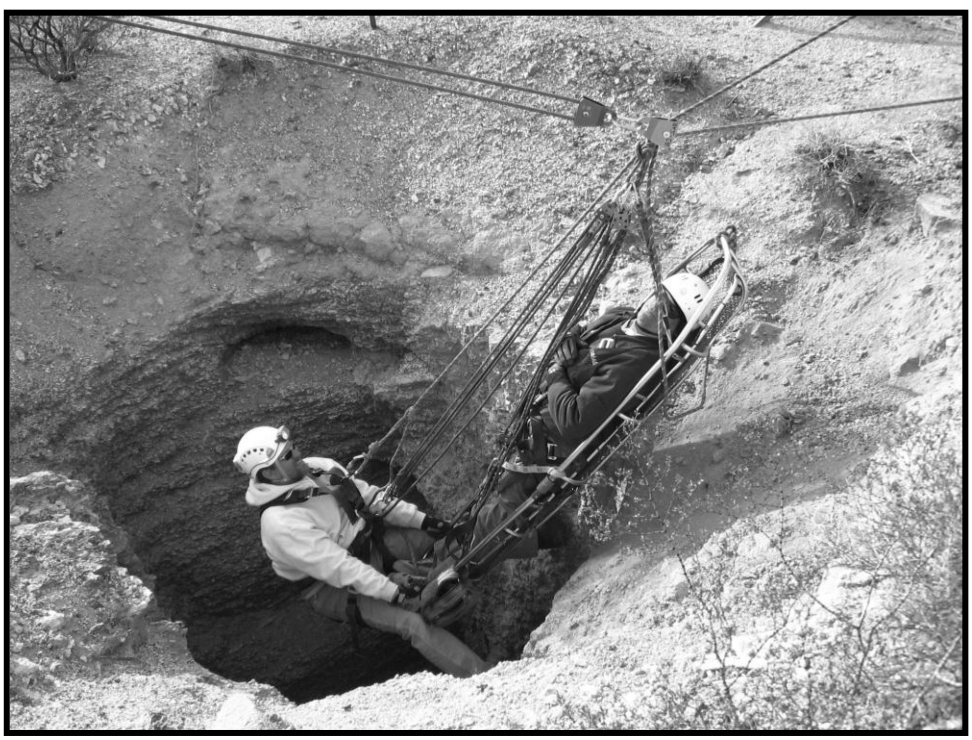
Front of litter:
Two – 2:1 MAs

Soft interface like quick-draws or small prusik loops must be used to connect the 2:1 MAs to the litter. This will allow for radical and quick movement of the litter system. Hard connectors tend to side load and bind in awkward position.

Foot end of the litter is secured with two prusik loops that yoke at the foot end to the mini 4:1cd.

The RescueRig Litter System will allow quick up and down configurations to meet extremely tight situations.

The RescueRig Litter System allows for an endless array of configuration possibilities that can safely, quickly, and easily be manipulated by a single attendant.



Patient Packaging

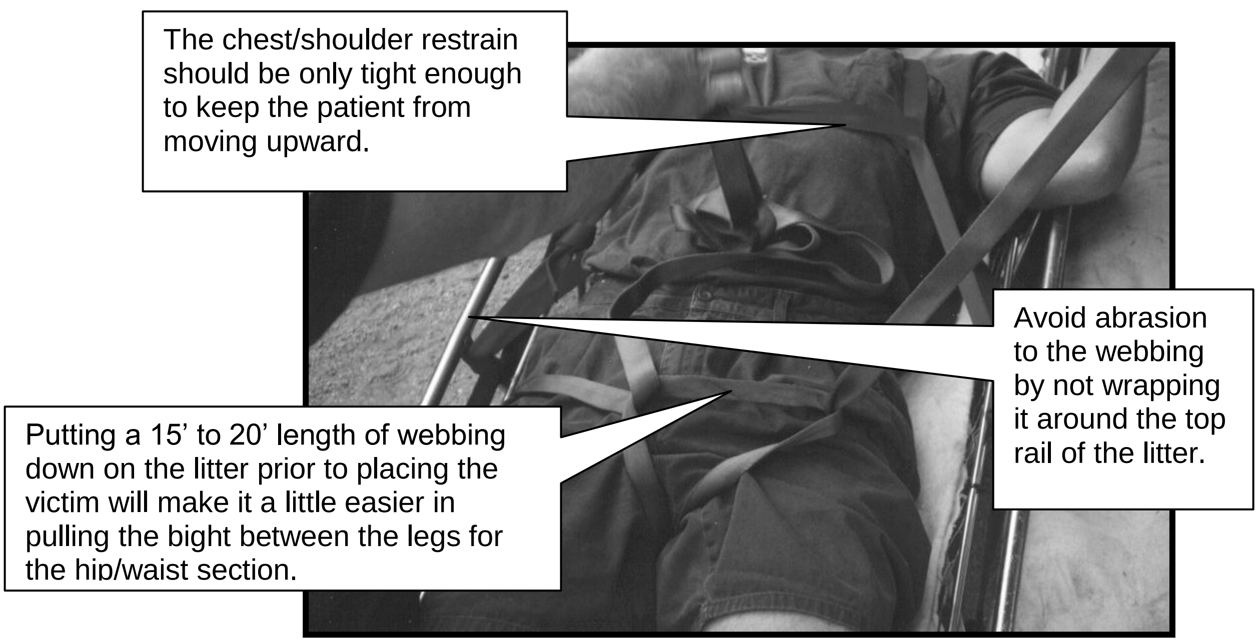
Patient packaging is the act of getting the patient ready to be evacuated. It is a preferred practice to get advanced life support treatment (ALS personnel, and equipment) to the victim as soon as possible. This usually means sending paramedic team members as quickly as possible while the rest of the team is working on the rigging for the extrication system.

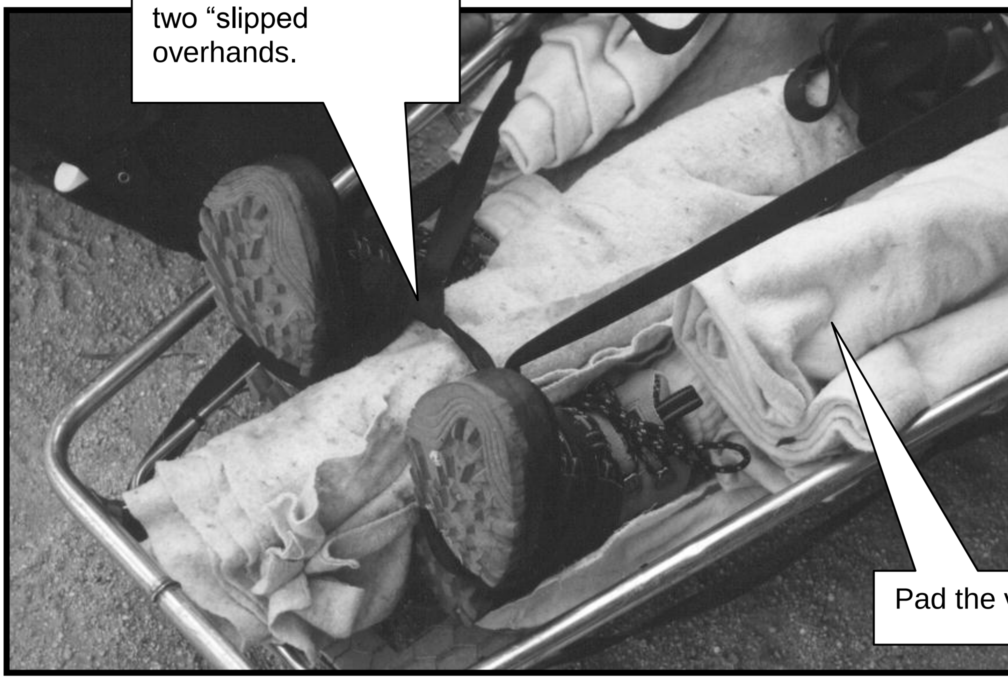
Technical rescue extrications are difficult at best. The victim needs to be secured, so that he/she cannot bounce around inside the stretcher or fall out if the stretcher is tipped.

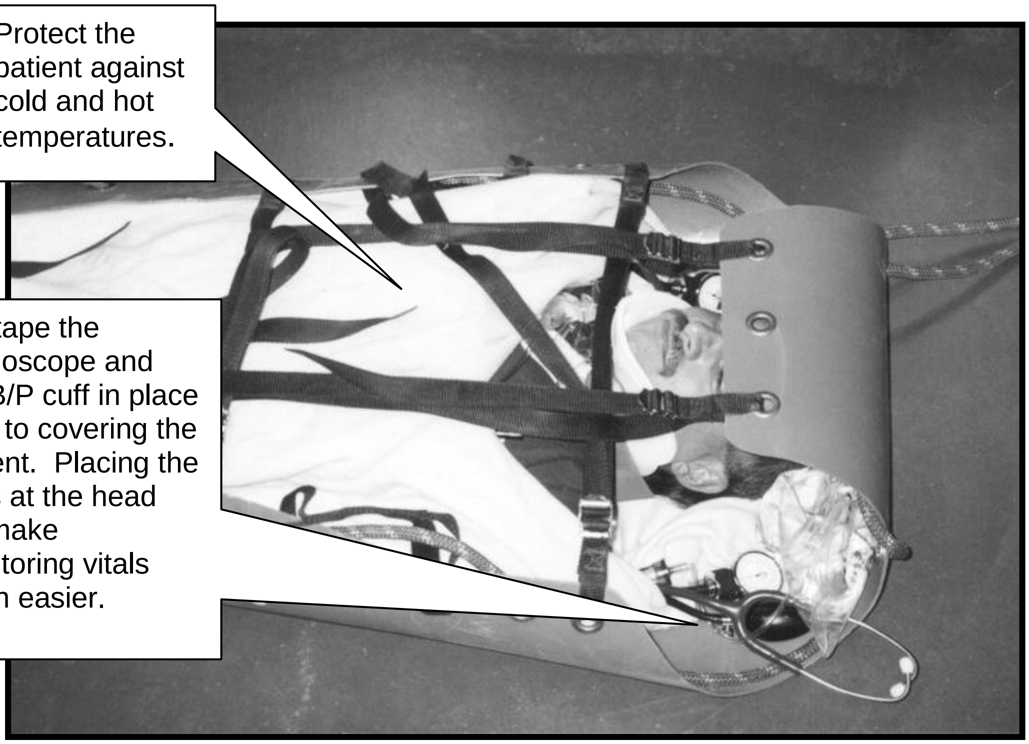
Once the rescuer(s) has located the victim(s), a quick primary survey of the victim should be done. If the condition of the victim allows, a thorough secondary survey, including a quick neurological exam, should be done.

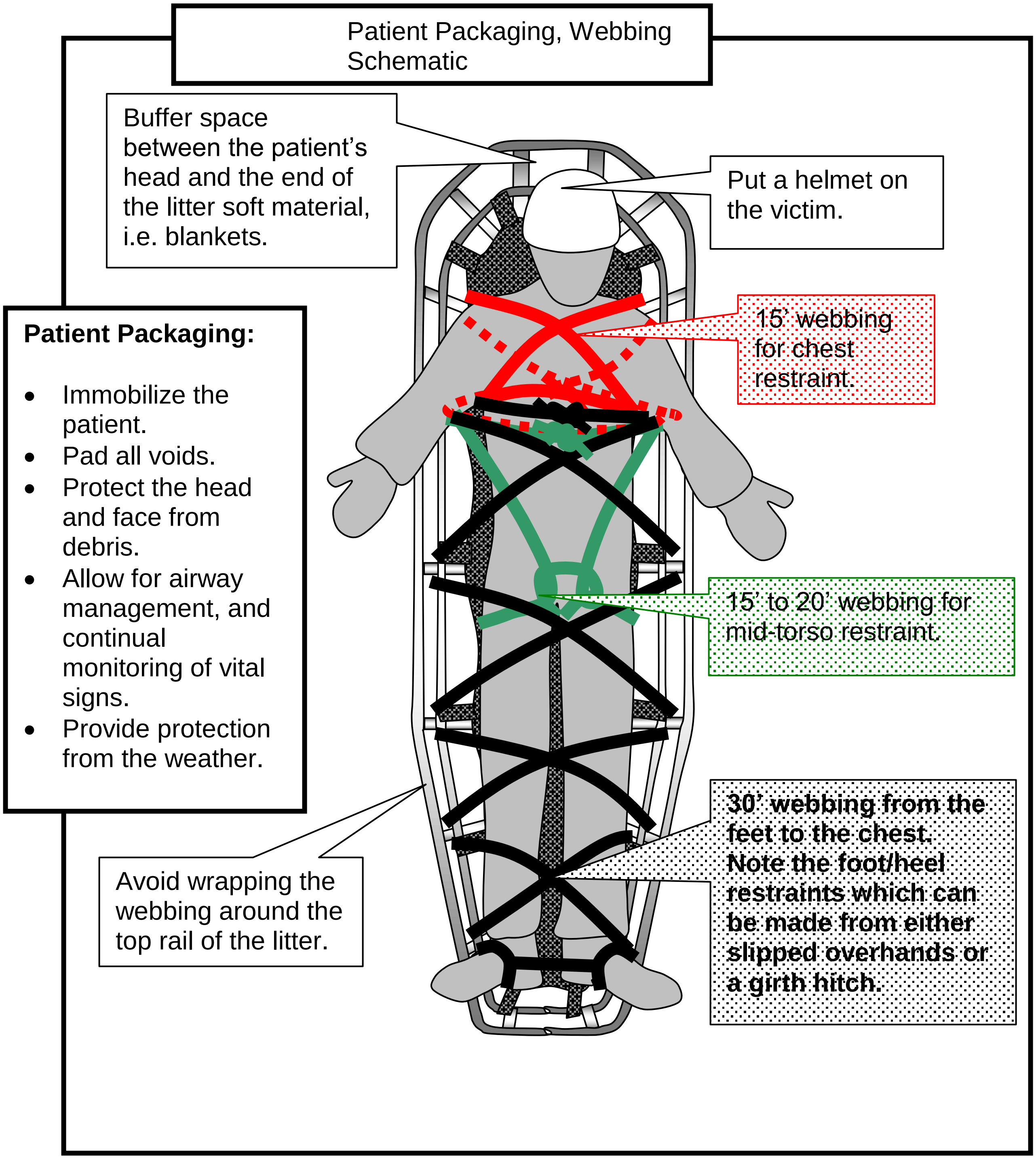
Pad all voids between the patient and the litter. After the application of the cervical collar a helmet and safety goggles should be placed on the patient (a litter shield eliminates the need for additional head and face protection for the patient.

Protected the webbing from potential abrasion by using the vertical struts of the litter and avoid wrapping webbing around the top rail. Two loops around the feet in the middle of the bottom 20' length of webbing will prevent the patient from downward movement. There are many different ways to secure a victim into an extrication device such as the litter basket. As long as the victim is secured properly, with no chance of falling out of the device, the rescuer has done his job.




At the mid-point of the bottom webbing, secure the feet with two “slipped overhands.
Pad the voids.

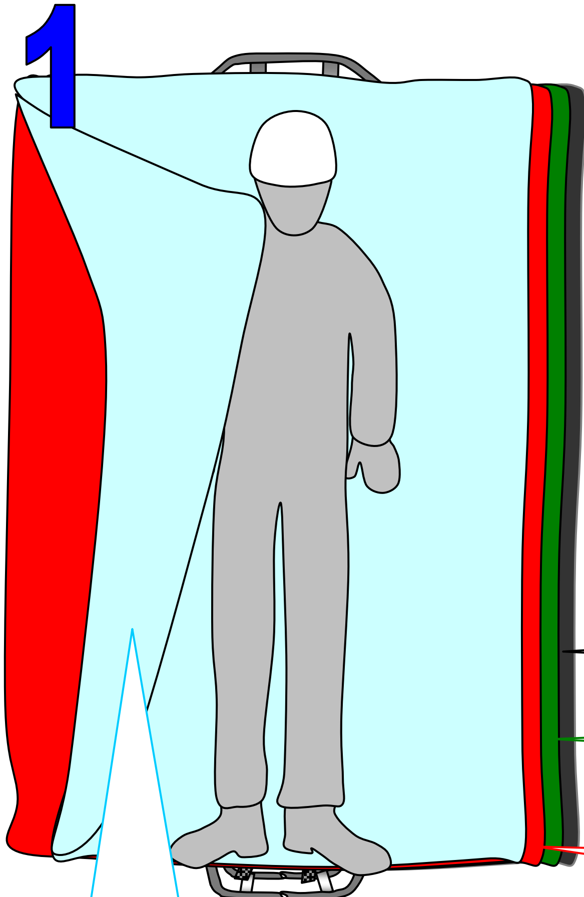

Protect the patient against cold and hot temperatures.
Pre-tape the stethoscope and the B/P cuff in place prior to covering the Patient. Placing the ends at the head will make monitoring vitals much easier.


Patient Packaging, Webbing Schematic
Buffer space between the patient's head and the end of the litter soft material, i.e. blankets.
Put a helmet on the victim.
Patient Packaging:
• Immobilize the patient.
• Pad all voids.
• Protect the head and face from debris.
• Allow for airway management, and continual monitoring of vital signs.
• Provide protection from the weather.
15' webbing for chest restraint.
15' to 20' webbing for mid-torso restraint.
30' webbing from the feet to the chest. Note the foot/heel restraints which can be made from either slipped overhands or a girth hitch.
Avoid wrapping the webbing around the top rail of the litter.

Patient Packaging, Hypothermic Layering.

Multiple layers is a very good way to insulate the victim from cold weather, and hypothermia, especially during extensive extrications.

The first layer, closest to the litter basket is moister proof, such as a tarp or black “landscape” plastic. Additional layers of blankets are added with the victim placed on the last blanket. When using sleeping bags, orient the zipper straight up (not on the side), this will allow easy access to the victim during extrication.

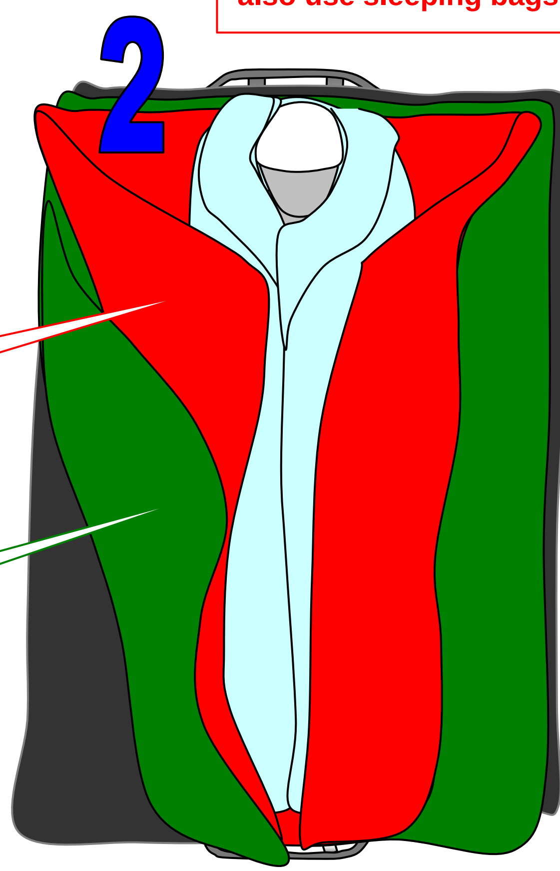


The black plastic, moister proof barrier is laid on the litter basket.

1st blanket layer on top of the plastic.

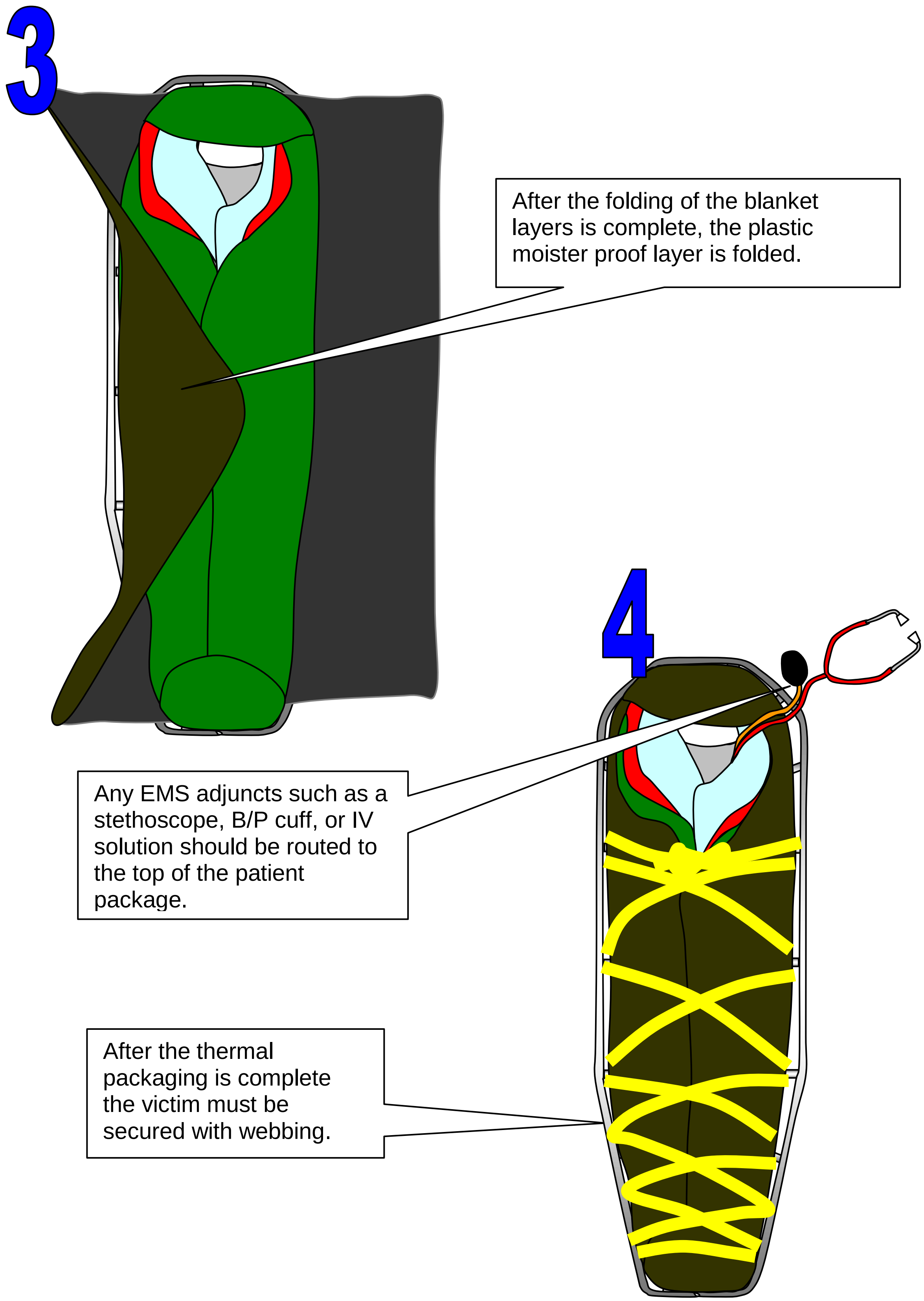
Middle blanket layers. (May also use sleeping bags.)

The last blanket layer is the first layer to fold back onto the victim.



Middle layer is than folded back.

The first blanket layer down is the last blanket to be folded over.


3
After the folding of the blanket layers is complete, the plastic moister proof layer is folded.
4
Any EMS adjuncts such as a stethoscope, B/P cuff, or IV solution should be routed to the top of the patient package.
After the thermal packaging is complete the victim must be secured with webbing.

Chapter 9, Rappelling and Ascending

Rappelling is a controlled descent down a fixed line. It is a basic tool for the high angle rescuer. There are several skills necessary to rappel safely and effectively, including proper technique, understanding belay systems, and knowledge of anchor systems.

As opposed to recreational or military rappelling, rescue rappelling is done in a slow and controlled manner. Rapid, bouncing rappels are a very unprofessional approach in reaching the victim. This kind of attitude can contribute to loss of control, rope damage, and potential system wide failure.

Always check your rigging, and have another team member double check your rigging, carabiners should be in the down, locked position. Make sure the helmet strap is secure, gloves are on, and hair is tucked in prior to beginning.

When rappelling, *never take your brake hand off of the rope*. Make sure to take appropriate ascending devices with you in the event self-rescue becomes necessary.

Rescue rappel operations should employ a separate belay line.

Selecting an anchor to rappel from is every bit as important as anchor selection for the system. Simply because the rappel rope is supporting a single person load doesn't lessen the fact that there is still at least one human life on rope, don't loose sight of this for the sake of speed.

The same principals that apply for system anchors also apply for rappel anchors. One difference between system and personal anchors is that system anchors will almost always incorporate an attachment that is separate from the system line, i.e. a wrap 3, pull 2 with webbing. Where as with rappel lines, it is acceptable to anchor the working end of the rappel line directly to the anchor.

The use of high directionals, ether natural or artificial, is highly recommended whenever possible. The higher above the waistline the rappel rope is anchored the easier it will be to negotiate the edge.

Conversely, take care in anchoring high, especially with natural high directionals, such as tree branches. When using tree branches pick one that is substantial, if possible, leave enough working end of the rappel rope to tie a back-up knot to the trunk of the tree.

Rappel Signals

Rappel signals include:

Rappeler	**Belayer**
"Belay On?" (Is belayer ready?)	"On Belay." (Belayer is ready.)
"Rappelling."(Rappeler is ready.)	"Rappel On."
"Slack." (Need slack in belay line.)	“Slack”
"Up Rope."	“Up Rope” (Belayer takes up slack.)
"Off Rope." (Rappeler finished and off)	

Signals anyone can make:

"Rock!" (A rock is falling overhead.)

"Stop!" (Cease all operations.)

"Falling!" (Rappeler is falling. Lock up belay line.)

OTHER CONSIDERATIONS

Don't step on rope or webbing.

Always pad edges or use edge protection.

Check, check and recheck.

Don't rush.

The simplest way is often the most effective.

Wear protective clothing when appropriate, including helmet, gloves, goggles, and nomex suit.

Remember to bring the victim a helmet and goggles.

Minimize the number of personnel near the edge.

Don't carry knives; use rescue scissors.

When in doubt, back it up.

Watch for side-loaded carabiners.

Avoid nylon passing on nylon.

Keep software away from acids.

Set and dress all knots.

Tie in when approaching or working near an edge.

Pay attention when belaying and never
take your brake hand off the belay line.

Don't assume it is safe just because someone else worked it out for you.

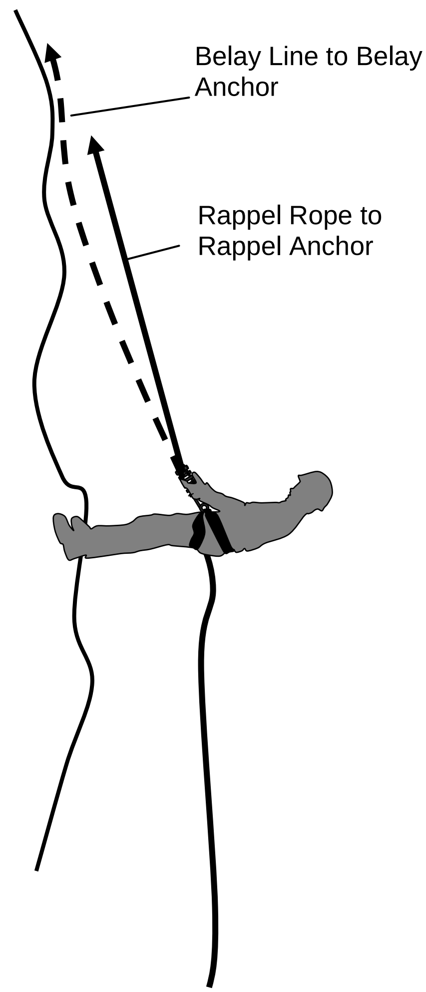
You have a right to question authority. Make sure you feel comfortable with a given situation.

Correct rappel posture is typically:

- Feet placement about the same width as the rescuer's shoulders, wider if the terrain type dictates the need.

- With the body at a 90 degree angle to the surface being rappelled.

The rescuer should employ a separate belay rope. The rescuer's end of the belay should be tied to a dedicated point of attachment separate from the rappel line. Preferably the rescuer end of the belay line should be tied in such a way that the connecting knot captures the waist harness and the chest harness.



Critical Thinking On Rappelling:
(The Importance of the Angle of the Rappel Rope)

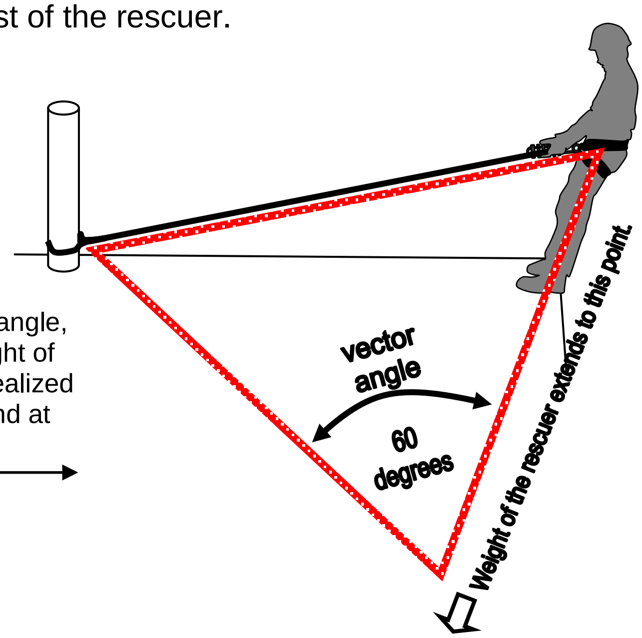
There has been much written on the subject of "edge trauma", or if you will, the psychological stress of taking that first step over the edge. We will tell you here and now that the physical aspects of rappelling play as big (if not bigger) role to "edge trauma" as that of psychological stress.

The importance of angles and their effect on rope systems can not be over emphasized. Larger angles will always create more rope tension somewhere in the system, depending on the location and function of the angle. This is readily seen in complex rigging such as highlines, based on the degree of the angle created by the vector of the load, immense forces are generated at each anchor. Multi-point anchors are often used in rope rigging to make one good anchor out of multiple questionable anchors, the angle between these multiple anchors becomes critical if the degree of separation is too large. A 90^o angle between to anchors will produce 71% of the weight of the load at each anchor, at 122^o, 100% at each anchor, and at 150^o, the weight of the load is doubled on each anchor!

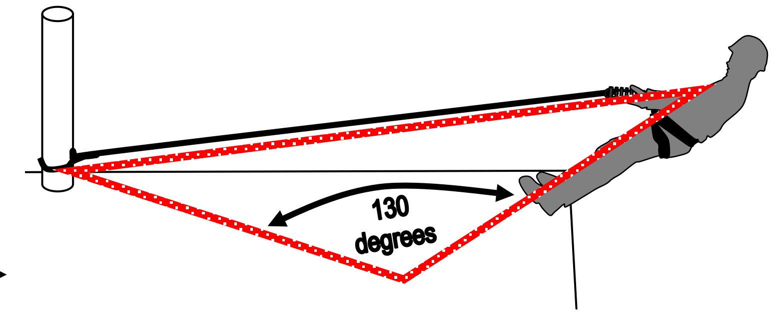
These forces also have a profound effect on rappelling as well, especially at the edge during the starting phase of the rappel. It is at this phase for a brief moment, which the rescuer absorbs the same force as the anchor he/she is rappelling from. Rappel rope that is anchored above the rescuer's waist offers much less physical stress (and sometimes, psychological stress) than if it is anchored below the waist.

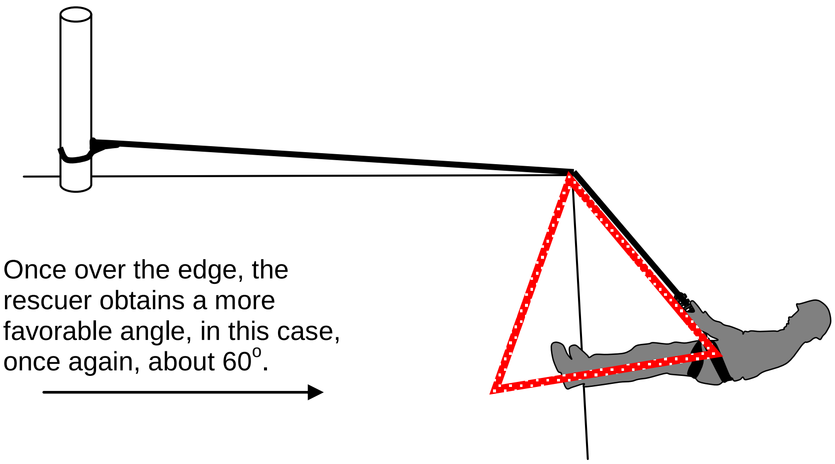
The physics of this stress may be visualized by extending the force of the feet of the rescuer thus creating a triangle between the anchor point closest to the edge, the waist, and the feet. By using the formula on pages 68, and 69 the angle formed at the apex of the feet will allow you to determine the tension at the anchor and at the waist of the rescuer.

At a 60^o vector angle, 57% of the weight of the rescuer is realized at the anchor and at the waist.



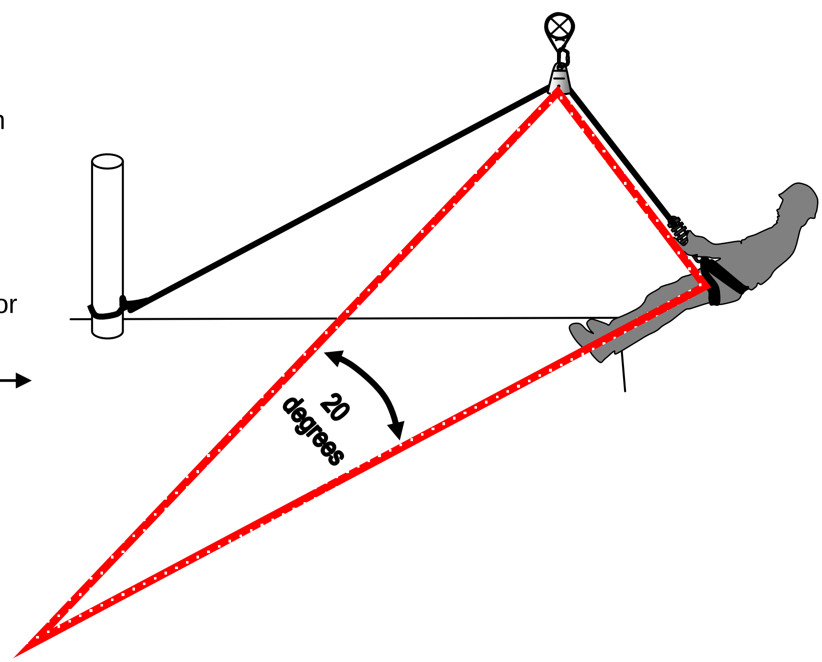
At a 130° vector, 120% of the weight of the rescuer is transferred to both, the anchor and the waist.





Once over the edge, the rescuer obtains a more favorable angle, in this case, once again, about 60°.

In this case, the use of a high directional has allowed the rescuer to make the initial approach to the edge with only a 20° vector angle, or 51% of his/hers body weight transferred both, to the anchor and the waist.



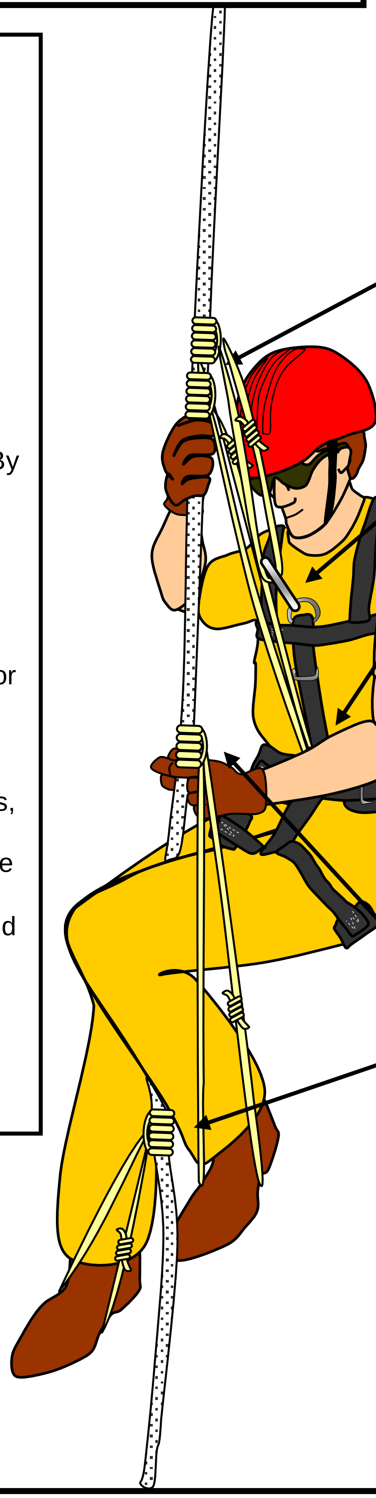
Ascending With System Prusiks

Rope may be ascended by using your pre-tied system prusik loops. There are various ways to use prusik loops, it is important that the rescuer practice with these tools and find a comfort zone that meets his/her's personal needs. The one commonality when climbing with prusik loops is that there must be two points of contact with the host rope at all times. As with all aspects of edge exposure, the rescuers must be on a separate belay line.

Two upper torso loops are typically connected to the chest harness "D" ring and the waist "D" ring. One or two long loops are operated by the feet. By alternating the weight of the rescuer between the chest loops and the foot loops, the climber will be able to adjust the prusiks upward (or downward) while ascending (or descending) the host rope.

In addition to system rope grabs and climbing, system prusik loops may be used to self-rescue, or negotiate a knot in the rope. This may be accomplished by:

- Prusik to the base of the knot.
- Standing as high as possible on the foot loops, while still attached to the original upper torso loops, attach two new upper torso loops above the knot.
- Weight the new chest loops and detach the old chest loops.
- Continue to prusik until the foot loops reach the knot. While suspended by the two new chest loops, reposition the foot loops above the knot.



Note:
The belay line has been omitted for clarity.

Section 1, Force Multipliers

Most rope technicians have some understanding of the Static System Safety Factor (SSSF) when analyzing their rope rigging. In short, the SSSF is identifying the weakest link in the system when the load is suspended and in a static state, not moving.

A force multiplier is any factor or condition that contributes to the over all stress of a rope system during a dynamic state. Rating this dynamic state or rope movement/stress is best represented as the Dynamic System Safety Factor (DSSF). In other words, what is our weakest link during the operation of our rope system at its point of greatest stress, typically during onset of a hauling process?

During the course of this chapter, we will examine (on an extremely basic level) five areas of misunderstanding in rope rigging commonly seen with emergency responders in the urban technical rescue environment; 1) Force Vectors, 2) Tensile Force 3) Compression Force, 4) Friction, and 5) Torque.

Rigging is not a game of chance; there are no educated guesses, every action and subsequent reaction is completely predictable!

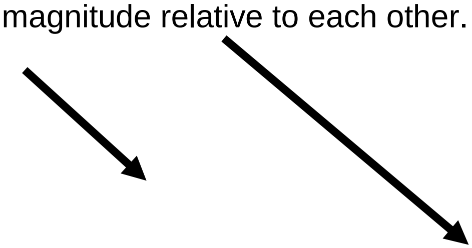
Force Vectors

To understand rigging is to understand at least some aspects of trigonometry and vector physics. The knowledge of angles, components, and resultants is synonymous to quality rope rigging. To study vectors is to study the physical qualities of force that has both direction and magnitude.

Lets do a recap on this subject from Volume One of Urban Technical Rescue, and than expand our study from there.

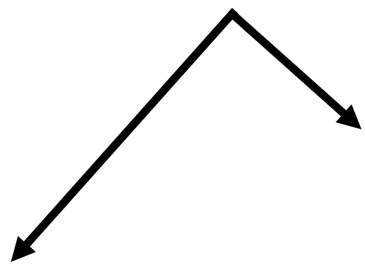
A force vector may be graphed or represented as a simple arrow, also more commonly referred to in math as a component. This component will always indicate the direction of the force.

When we compare the length of one force vector component to the length of another force vector component, we not only have the direction of each vector, but we now can compare their magnitude relative to each other.

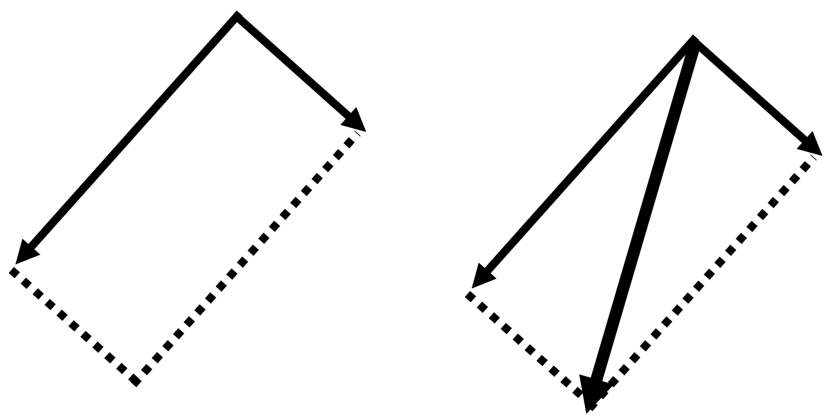


Therefore, the component that is the longest has a greater magnitude. In fact, simply by comparing the two components we could deduct that the second is about 2 times more powerful or stronger than the first.

When two components come together we have now created an angle. The resultant is the force vector that is created by the joining of these two components.



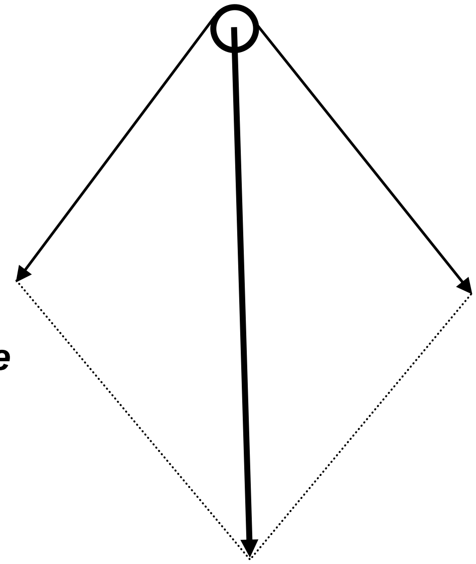
To determine the resultant draw a parallelogram from the given angle. Than draw a new line (component) from the original angle (resultant) to its opposite angle of the parallelogram. By comparing the length of the resultant component to the components of the angle, we can easily see which component of this system is producing the greatest force simply by determining, which is the longest.



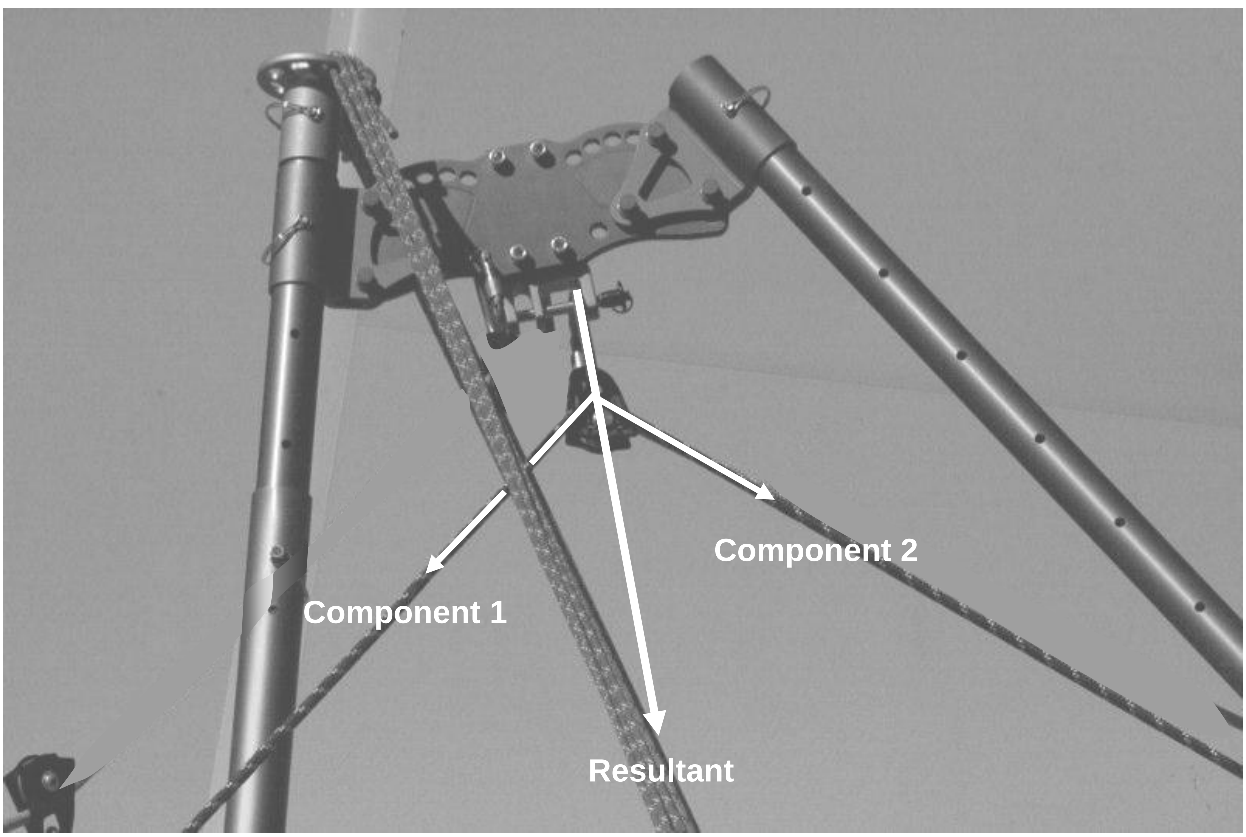
When components of rope go through a pulley, the pulley equalizes the components of rope and renders them equal. The resultant (in this case, the pulley) will always seek the location halfway between the two rope components.

The center of any tensioned pulley will always point to the exact location and direction of the resultant force at work on the associated anchor.

Again, the resultant of any pulley will find the middle point between the legs of rope going in and coming out of the pulley. The use of the parallelogram still works well in determining the resultant force, its direction and magnitude.

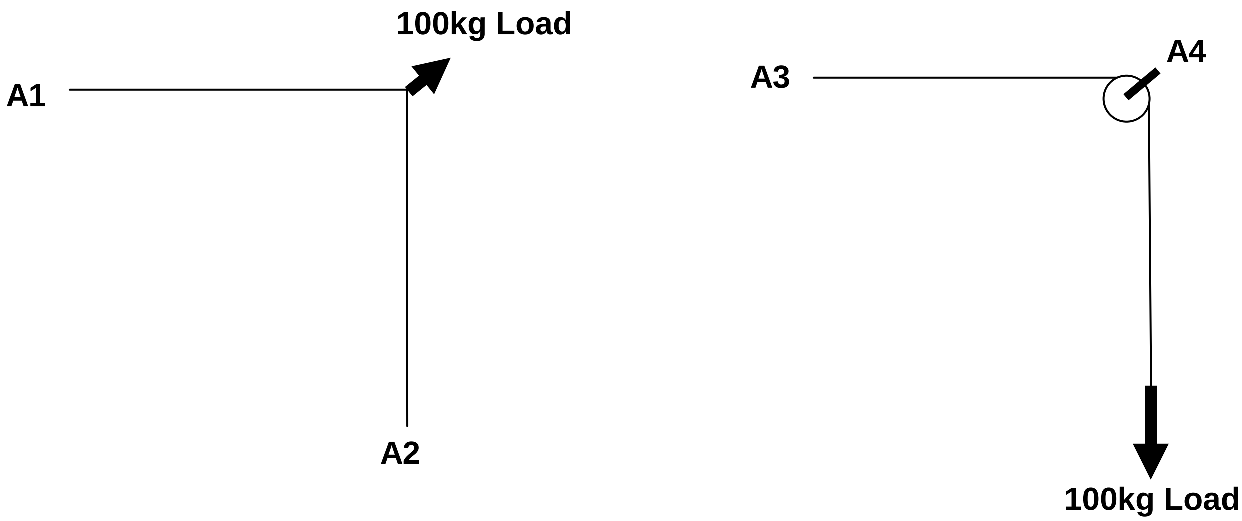


The resultant of a pulley is the absolute indicator of where the force of that pulley is directed.



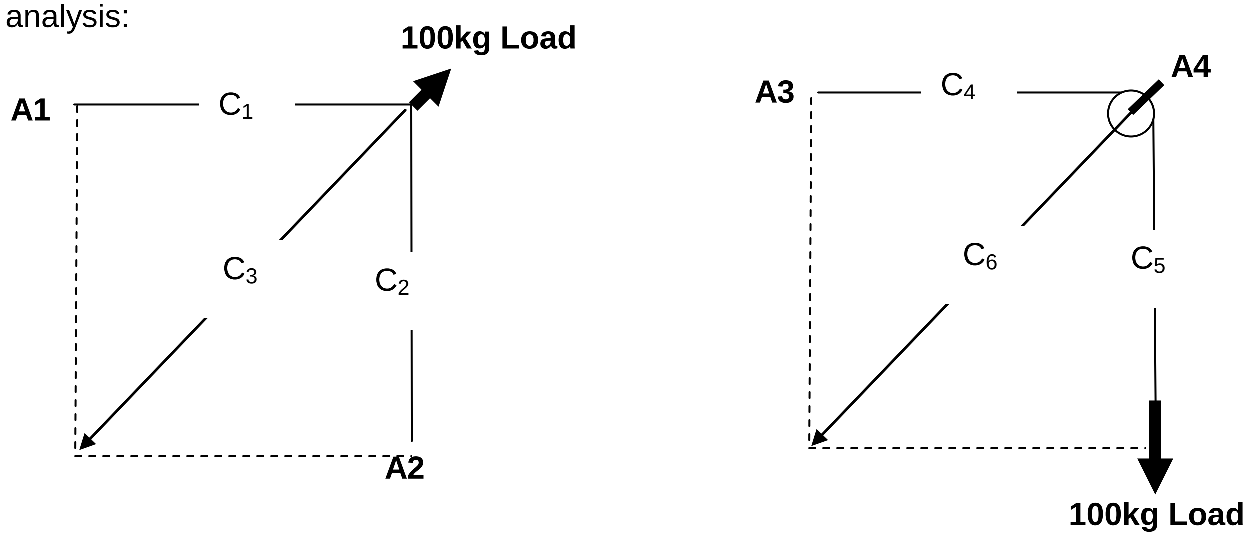
One of the most misunderstood issues of rope rigging is the analysis of the angle of a multipoint anchor system versus the same angle of a directional pulley. Most rope rescue personnel have committed to rote memory that with a 90^o angle, each anchor of a 2 by1 multipoint anchor system will receive 71% of the load, or with a 150^o angle each anchor will receive 200% of the load. Given the same angles of rope going in and coming out of a directional pulley, when asked to give the force on the directional pulley anchor, many rescuers will erroneously give the same answer.

Study the two right angle rope systems below; both have two anchors and both support a 100kg load. What percentage of the load is each anchor receiving?



If you said A1 and A2 receive 71kg; A3 receives 100kg; and A4 receives 141kg you would be correct.

Let's look at these right angles again and apply our parallelogram/resultant analysis:

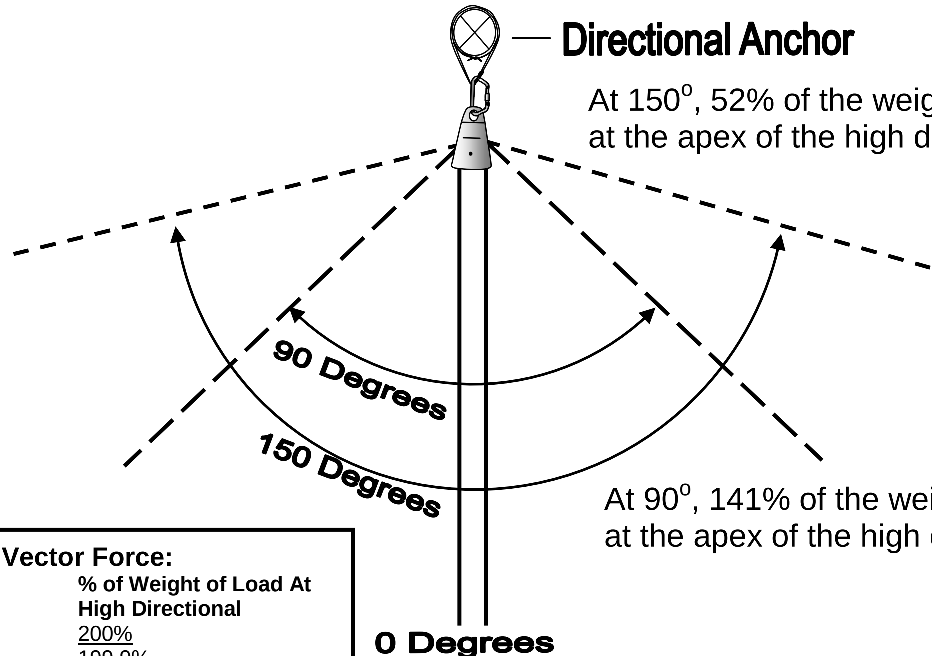


The 100kg load is our known value, what ever component the load is connected to represents 100; the remaining two components may now be assigned a value simply by comparing their length. C3 = 100, therefore C_1 and C_2 are 71% of C_3. C_5 = 100, therefore C_4 = 100% of C_5 and C_6 = 141% of C_5.

Although using parallelograms as mentioned above to determine the resultant of any given angle is a good rule of thumb method, ultimately, for field application we must commit to rote memory the recognition of angles as they apply to either, 1) multipoint anchor systems, or 2) directional pulley anchors.

Force Vector Formula for Directional Pulley Anchors

Force Vector = $\text{COS}\,\frac{\angle}{2}(2)$ (< = vector angle)



At 150°, 52% of the weight of the load is at the apex of the high directional.

At 90°, 141% of the weight of the load is at the apex of the high directional.

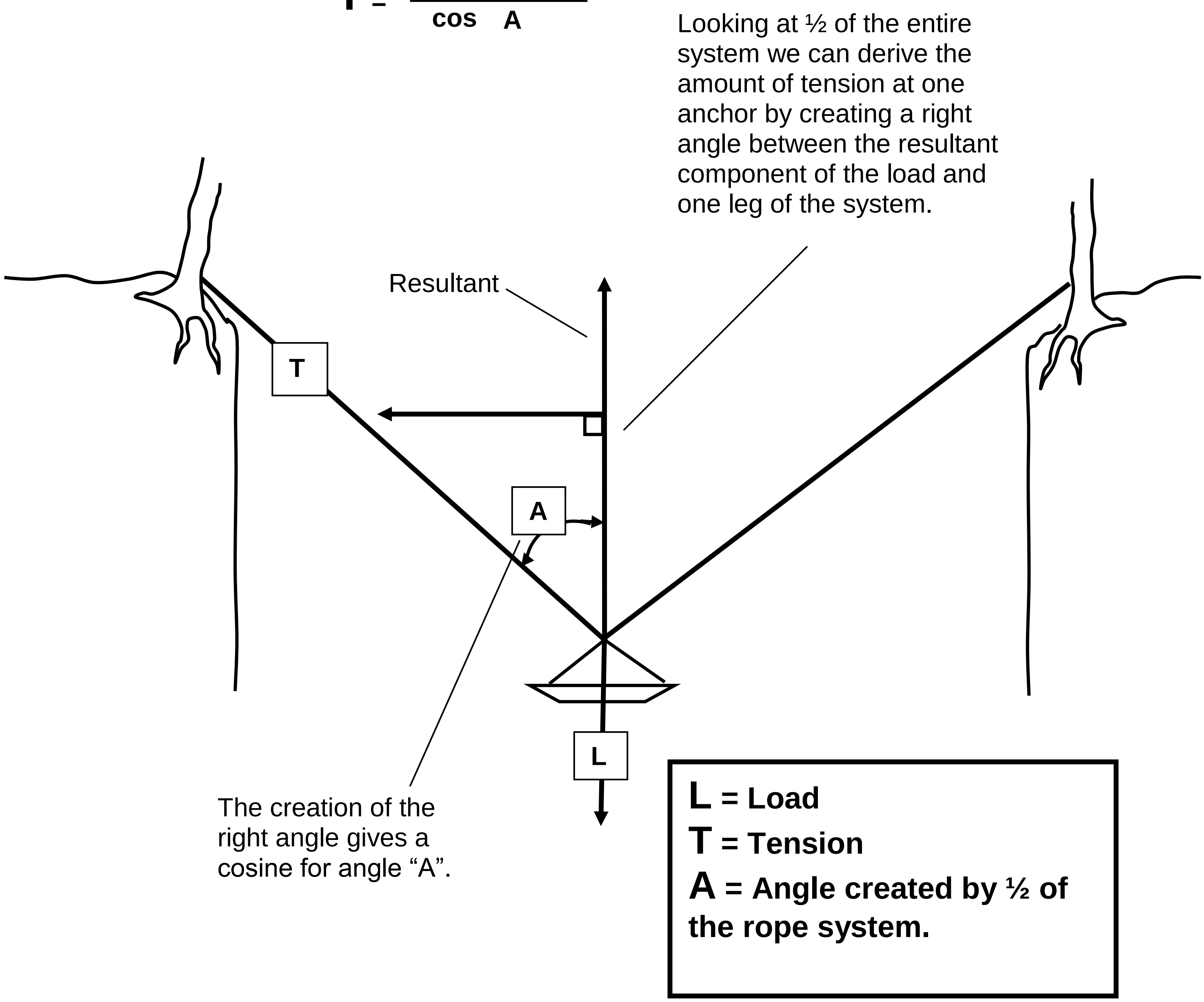
At 0°, 200% of the weight of the load is at the apex of the high directional.

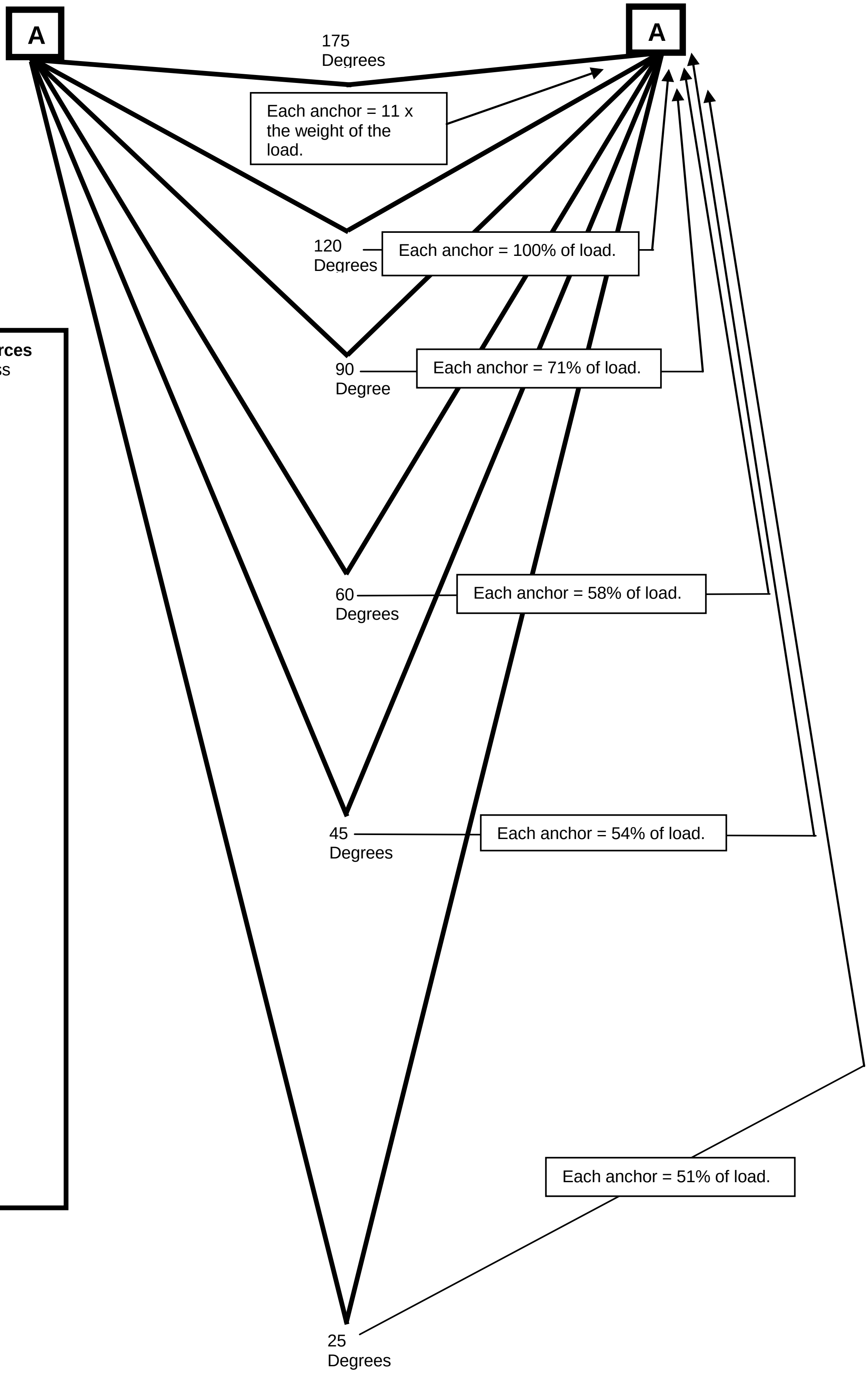
High Directional Vector Force:

Degree of Angle	% of Weight of Load At High Directional
0	200%
5	199.9%
10	199%
15	198%
20	197%
25	195%
30	193%
35	191%
40	188%
45	185%
50	181%
60	173%
65	169%
70	164%
75	159%
80	153%
85	147%
90	141%
95	135%
100	129%
105	122%
110	115%
115	107%
120	100%
125	92%
130	85%
135	77%
140	68%
145	60%
150	52%
155	43%
160	35%
165	26%
170	17%
175	8%
180	0%

Force Vector Formula for Multipoint Anchors

$$T = \frac{\frac{L}{2}}{\cos A}$$





Anchor Vector Forces

Degree	% of Mass
0	.5
5	.5005
10	.502
15	.504
20	.508
25	.512
30	.518
35	.524
40	.532
45	.541
50	.552
55	.564
60	.577
65	.593
70	.611
75	.631
80	.653
85	.678
90	.707
95	.74
100	.778
105	.821
110	.871
115	.931
120	1.
125	1.08
130	1.18
135	1.31
140	1.46
145	1.66
150	1.93
155	2.31
160	2.87
165	3.82
170	5.75
175	11.36
180	56.

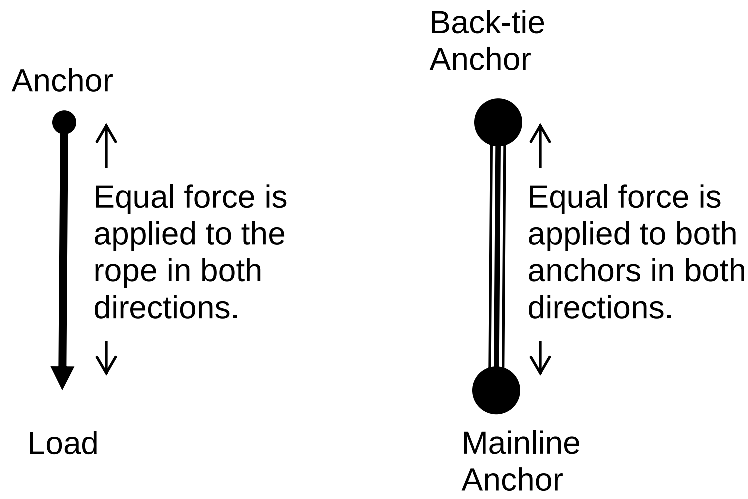
Tensile and Compression Force

In the application of rigging, we will discuss tension and compression at the same time. Most of us associate units of tension with the study of pulleys and mechanical advantage systems. While this is very true, indeed a critical component of pulley systems, the same physics that characterize tension in the study of pulley systems is also applicable to every single act of rope rigging. The instant a single piece of rope is tied and loaded, units of tension become a factor.

Compression force is the opposite of tensile force. As with all forms of construction, (rope rigging included) one can not exist without the other. One of our best examples of the use of compression in technical rescue can be found when we use a tripod as an elevated anchor point (high directional). For our purpose, the tripod does not become stable until the tensile force of the hanging load is applied, allowing the compression of the three legs to oppose the tensile force of the load. Both must take place in harmony for us to have a workable rigging system.

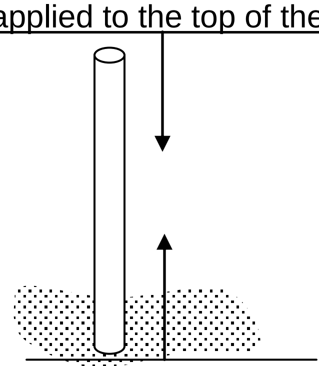
Not only must harmony exist between tension and compression, there must be equal harmony with all aspects of rigging physics. The bottom line revolves around the anchors. Will they hold, or won't they? What is the exact force vector being applied to the anchor? What is the resultant on the anchor? Is there an adequate amount of tension/compression at work to guarantee the integrity of the anchor?

Tensile Force can be defined as a pulling or stretching force that is applied equally between to points acting in opposite directions. Reducing tension and compression to their simplest state…at least in our world rigging…we are talking about two possibilities, load pulling against an anchor, and/or an anchor pulling against an anchor.



Compression Force can be defined as two forces of equal magnitude pushing on both ends of a solid object.

Force is applied to the top of the bar.



Equal opposing force is applied to the bar from the ground.
System failure will usually occur when tension exceeds compression.

Once again; system failure may occur when tension exceeds compression. Either the rope will break or the compression member of the anchor system will skid, bend or break.

All of this tension/compression pie-in-the-sky stuff sounds good, but how does it affect us in the real world of rescue rigging, specifically anchor construction? Do we really need to understand what the bending moment is of an oak tree or a steel “I” beam to be journeymen riggers? Do we really need to understand the modulus of static rope to effectively back-tie a marginal anchor? The answer is yes and no; someone in this grand and complex world of rope rescue has and continues to calculate the exact performance of the equipment we use. Manufacture standards such as NFPA 1983 give an additional layer of protection for the user in guaranteeing the quality of modern rigging gear. Most seasoned rope rescue technicians don’t need a detail mathematical foundation. Having said this; the higher the technician climbs up the ladder of his/her’s rigging career; assistant instructor; lead instructor; research and development; the more these issues of physics and math come to the surface.

Note the 9mm rope employed in the tensioned back-ties connected to the TerrAdaptor Lashing Ring; even though these back-tie ropes are only rated for “Lght” use per NFPA 1983, they are well above a 20:1 safety margin in this 2 person rescue load application. This is based on accurate tension and compression analysis performed by informed veteran rope rescue technicians.

Let’s look at the relationship between a vertical compression member and a tensioned member of an elevated anchor system; more specifically, what is the stress on the tension member, and how does this effect our anchor and equipment selection? Keep in mind this is a single dimension analysis; with additional tension members back-tie/guys and/or additional compression members typical to “A” frames, the distribution of tensile and compressive stress would be based on the respective angles of each members, hence, becoming a two dimensional analysis.

We must first calculate the resultant force placed on the apex of the high directional by the components of the loaded mainline.

Secondly, we will calculate the leverage ratio of the compression member over the tension member.

Last, we will calculate the ratio of the resultant force over the leverage ratio.

Stress of a single tension member of an elevated anchor system. $= \dfrac{(M)(\mathit{Sin}\ C)}{\mathit{Sin}\ T}$

C = the angle created by the resultant component of the high directional pulley or the vector force that is attached to the top of the *compression* member of the elevated anchor system.

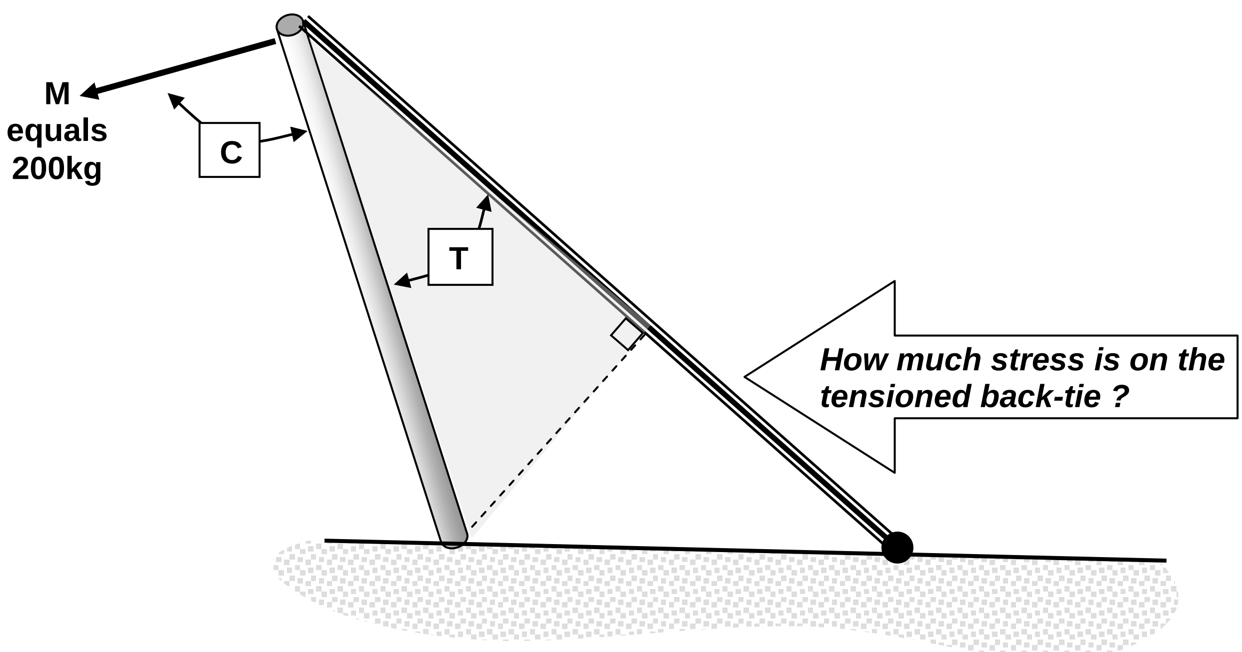
T = the angle at the top of the HD where the *compression* and *tension* members join.

M = the *magnitude* of the resultant component.

Note: These examples assume the skid factor of the compression member has been addressed.

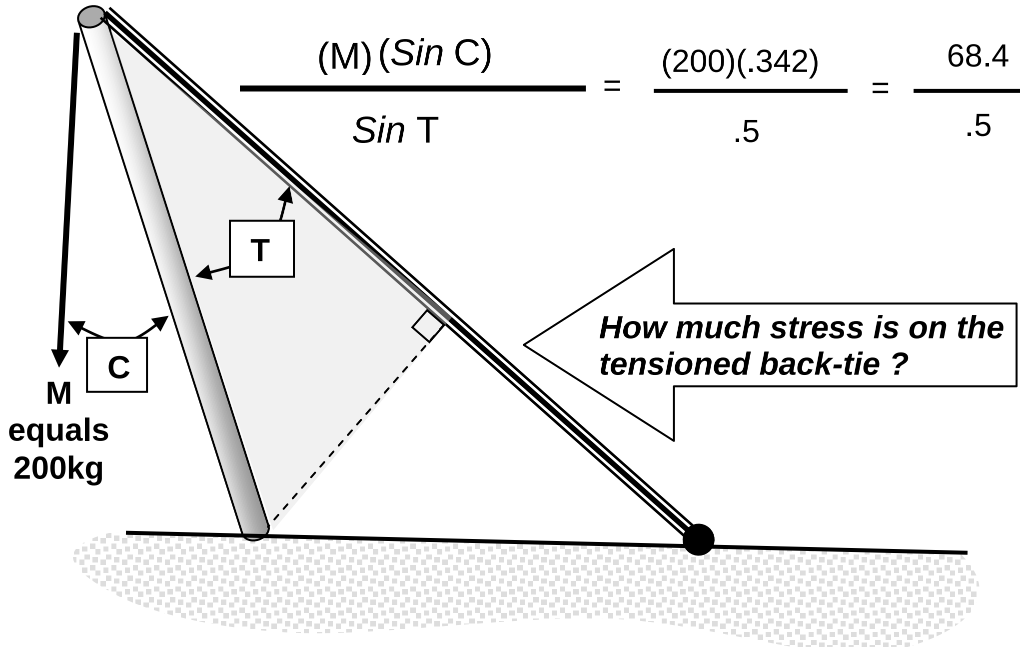
Example One; "M" equals 200kg; angle "C" is 90^o to the compression member. (Maximum leverage); angle "T" is 30^o.

$$\frac{(M)(\mathit{Sin}\ C)}{\mathit{Sin}\ T} = \frac{(200)(1)}{.5} = \frac{200}{.5} = \mathbf{400kg}$$



Example Two; “M” equals 200kg; Angle “C” equals 20°; angle “T” is still 30°.

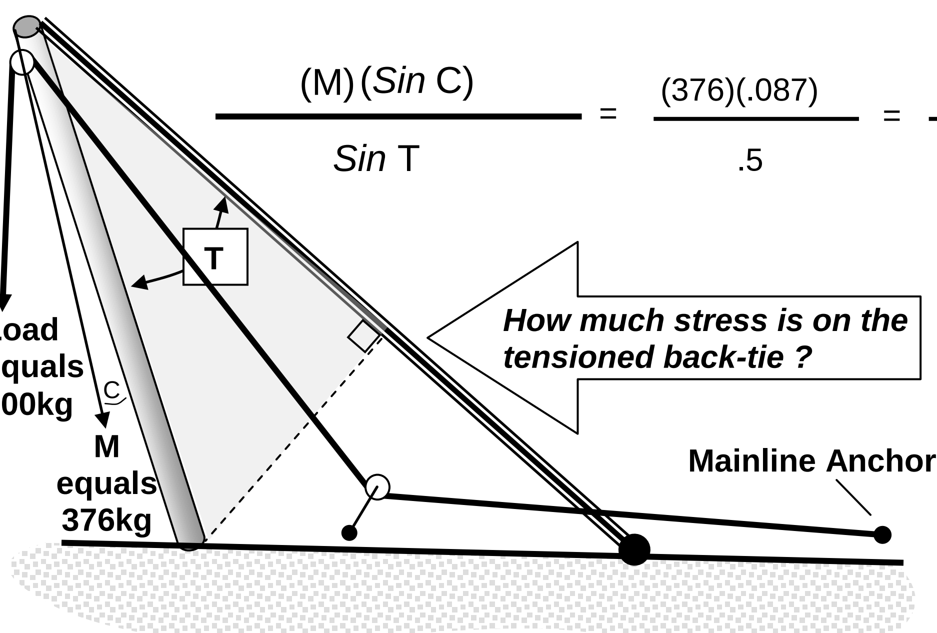
$$\frac{(M)(Sin\ C)}{Sin\ T} = \frac{(200)(.342)}{.5} = \frac{68.4}{.5} = \mathbf{136kg}$$



Example Three; Angle “C” equals 5°, typical leverage from a HD (high directional) pulley resultant acting on a single compression member. Angle “T” is still 30°.

The angle of the mainline going in and out of the HD pulley is 40°. **“M”**, the magnitude of the HD resultant, is 188% of the 200kg load equaling 376kg.

$$\frac{(M)(Sin\ C)}{Sin\ T} = \frac{(376)(.087)}{.5} = \frac{32.7}{.5} = \mathbf{65kg}$$



Friction

Rigging is the use of tension and compression to either move something or to keep something from moving. Whether we are moving or holding something, friction is always there, working for us or against us. This section on friction is a basic treatment of friction coefficients with a specific focus on how it will multiply the weight of the actual load during a hauling.

It is common practice in rope rescue to use a friction device such as a brake rack for the addition of friction during a lowering. When the mainline come in contact with the edge during a lowering it is as if an additional brake rack has been added. Aside from any rope wear and tear of continual edge contact, this edge friction is working in our favor.

Now let's convert our lowering to a raising system; the same edge contact that was working in our favor on the way down is now playing tug-of-war with the haul team! A matter of fact, a good rule-of-thumb measurement is about 3 times the weight of the load is really what the haul team has to overcome when the rope is being pulled over a rock ledge. This is arguably the single most important reason for the use of elevated anchor systems (i.e. the Vortex Multipod) over difficult edges.

At the beginning of this chapter, I mentioned Dynamic System Safety Factor (DSSF). Traditionally, we have always perform a Static System Safety Factor (SSSF) prior to the implementation of a rope rescue; we analyzed our rigging and made a judgment of the weakest link and whether or not it was within the parameters of our safety margin, usually a 10:1. The DSSF on the other hand, judges the rigging system during its operation, and predicts the weakest link during the greatest moment of system stress? This moment of greatest stress will always be during the transition between a static state to a state of hauling, or put into physical terms; the *transition from static friction to dynamic friction (sliding friction).*

Friction Law

Friction is a force of resistance between two objects that tends to oppose any motion. Friction may be further defined as being either static friction (force that tends to counter motion of an object that is in a state of rest, and kinetic friction (force wanting to slow an object in motion).

Coefficient of Friction

The coefficient of friction (μ) between an object and the surface it is at rest can be defined as the ratio of the applied force (f) needed to move the object divided by the normal force between the object and the surface (n).

$$\mu = f / n$$

In rigging; what is the ratio of the amount of force (stress on the rope system) need to initiate the hauling process divided by the loaded mainline at rest on a given surface prior to the start of the haul? Obviously, the higher the coefficient of friction the more stress to the haul system.

Dynamic Friction
After the initial spike of needed force to move the object from a state of rest the dynamic friction (sliding friction) is the force needed to sustain movement over the surface.

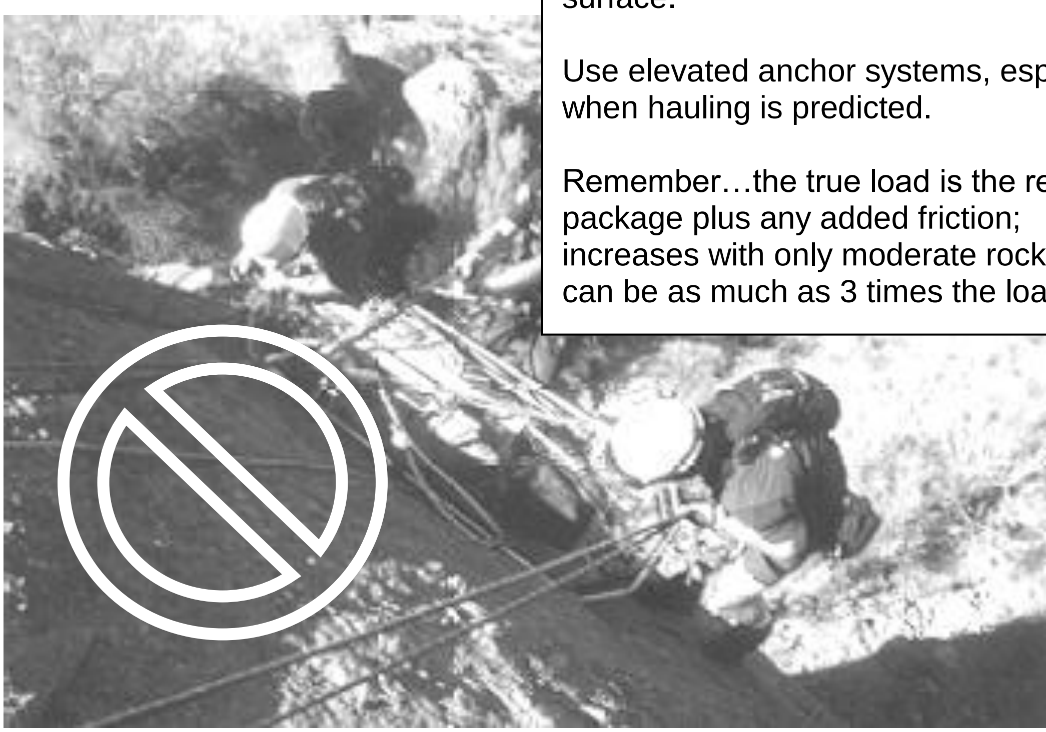
The only true way to establish the coefficient of friction of any given surface is through detailed analysis in a laboratory setting.

Although we have performed multiple informal slow pull test of a 50 pound load over a sandstone edge and steel hand rails at 90^o contact surface, we have found the best and simplest way to prove this point in the classroom is through the use of tabletop demonstrations by raising a 5 pound weight over a brick or metal pipe on the edge of the table. We usually use 6mm rope connected to the 50 pound rated dynamometer (fish scale). Going down, the 5 pound weight will register around 1.5 to 2 pounds on the scale; coming up the same 5 pound weight will register around 18 plus pounds on the scale. The results of these small scale classroom demonstrations are remarkably close to the test we performed with 50 pound loads over a sandstone edge; a dynamic coefficient of friction of about .35 or a magnification of the load by approximately 3 times during the hauling process. The hand rails proved little relief with an increase of the true load of about twice as much.

Avoid excessive rope contact with any surface.

Use elevated anchor systems, especially when hauling is predicted.

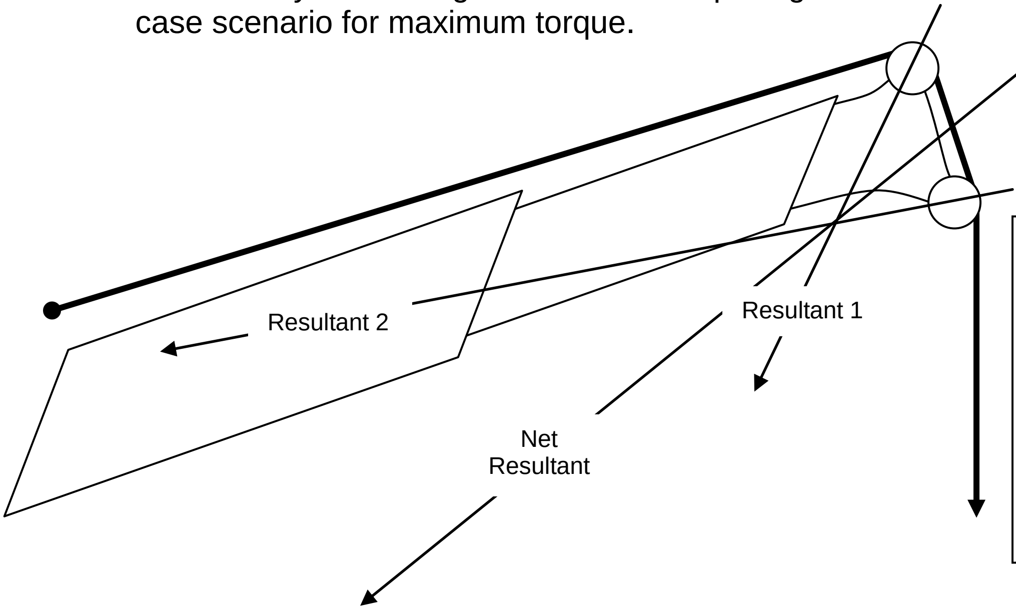
Remember…the true load is the rescue package plus any added friction; increases with only moderate rock contact can be as much as 3 times the load!



Torque

Torque has been included in this chapter because of the importance it plays in the use of high directional anchor systems. No where is this physical factor more evident than in the use of aerial ladder/platforms employed by fire service rope rescue teams as elevated anchor points.

A good lesson can be learned from simply observing construction cranes. This is in essence exactly what we are doing when we use aerial ladders for our elevated anchor points in rope rescue. As with all cranes, aerial ladders are huge class one levers…not tripods. As with any elevated anchor system, the resultant of the mainline system at the tip of the high directional is the most critical element in maintaining the integrity of the system. The basic theory of crane operation is to keep the resultant of the mainline system at the tip of the HD as close as possible to the compression of the crane, or in our case, as close as possible to the compression of the aerial. The closer the mainline resultant of the HD pulley gets to 90^o with the aerial, the more the torque there is at the pedestal and the more bending moment there is along the length of the aerial itself. Unfortunately there are some publications on the market that are incorrect and actually show diagrams that are depicting the use of aerials at close to a worse case scenario for maximum torque.



Typical crane physics
The net resultant is operated as close as possible to the compression of the crane, therefore maximizing compression and minimizing torque.

Aerial ladders should also minimize torque through the manipulation of the mainline resultant at the HD pulley.

Another bad assumption in the use of aerials for rope rescue is relying on the manufactures ratings of maximum dynamic loads under *firefighting operations*. Firefighting ratings are assuming water flow and the weight of water in the standpipe distributed along the full length of the aerial. In addition, when the master stream is in operation there is a reverse thrust that is actually reducing the potential torque. Rope systems on the other hand, create a singular force of torque on the aerial towards the ground.

Here are some basic rules for using aerial ladders for elevated anchors in rope rescue:

1. Minimize the load; victim only when ever possible.

2. Maximize the degree of aerial elevation.

3. Minimize aerial extension.

4. Minimize vertical torque by rigging the mainline resultant as close as possible to the compression of the aerial.

5. Minimize horizontal torque by rigging the mainline inline with the aerial.

6. Never rig the belay line at the tip of the aerial. Either operate the belay from the structure the victim is being extricated from, or consider using a single rope technique when no other belay option is practical. A dynamic event causing the deployment of the belay system could be catastrophic.

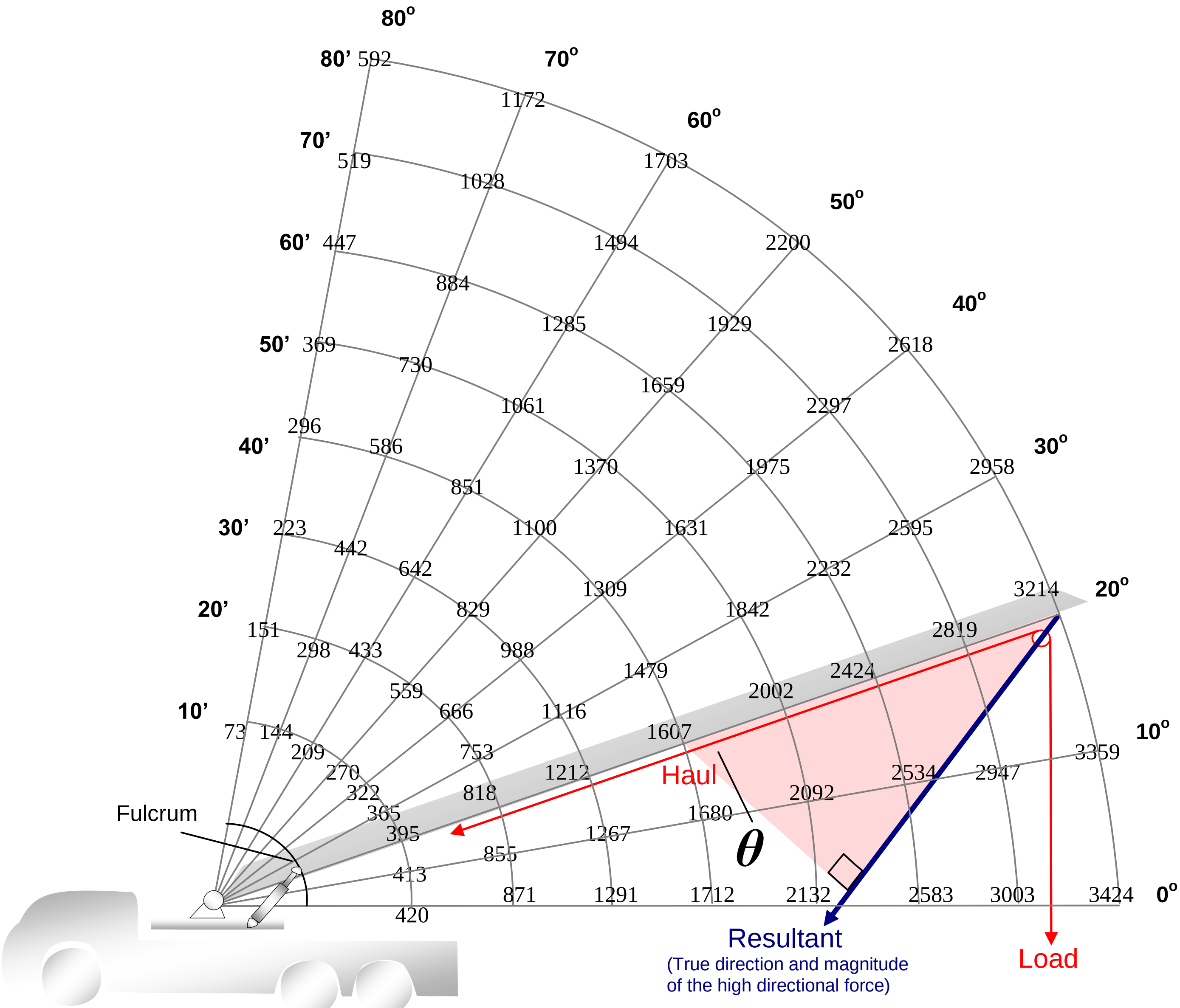
7. Use larger haul teams, this will promote smoother control of the mainline and much less shock loading that is typically seen by a small number of haulers that are forced to use jerking pulls.

The next two pages contain torque calculations based on the rigging of the mainline through a high directional pulley versus the rigging of a 4:1cd at the tip.

It should also be noted that these are static calculations. The only way to get a true dynamic representation of the actual load during the hauling process is through the use of a load cell between the tip of the aerial and the mainline HD pulley. Through limited testing, we confirm our suspicions that when the MA is operated on the ground, a larger haul team may be used therefore promoting a smoother haul and substantially less shock force to the aerial. Conversely, when using the 4:1cd at the tip of the aerial, only one or two haulers at the most are typically used because of limited space around the hole; this promotes shock loads as much as five time higher due to the jerking motions of the limited haulers.

Torque on the Fulcrum or the Weakest Link of an Aerial Ladder

(4:1cd versus Single Directional Pulley)

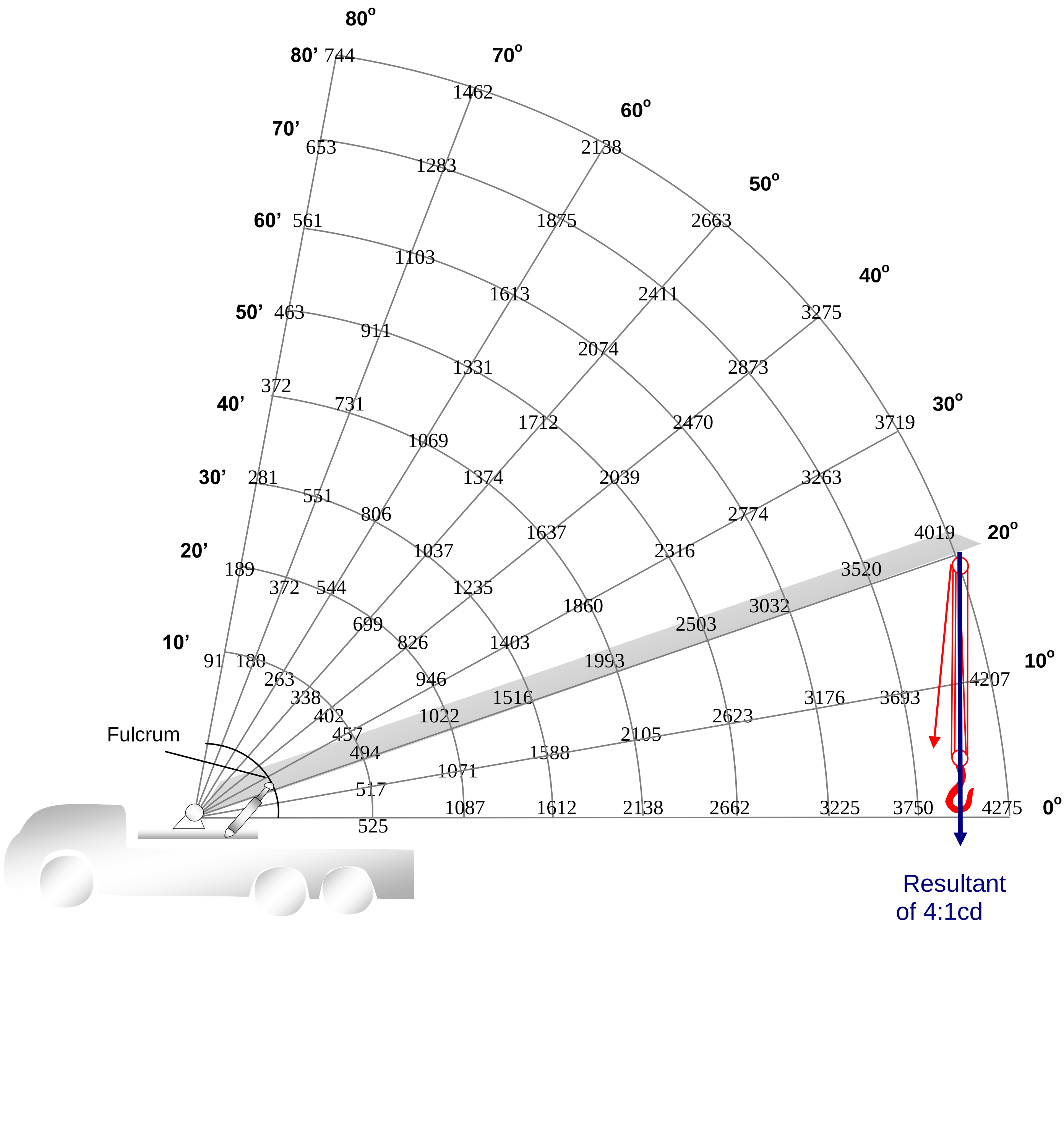


- Calculate the resultant of the HD for load at the tip (see last page for resultant formula).
- Calculate the leverage ratio on the fulcrum (ram) using:

Length of aerial above fulcrum **/** ***7 feet***

- Create an adjusted right triangle, using the resultant as the opposite and the aerial as the hypotenuse.
- Formula is: *(Tip Load)(Leverage Ratio)(cosine* θ *[Adjusted Angle])*

The Load in this example is 300 lbs.



80o
80’ 744
70o
1462
70’
653
60o
2138
1283
50o
60’ 561
1875
2663
1103
40o
1613
2411
50’ 463
3275
911
2074
1331
2873
372
30o
40’
731
1712
2470
3719
1069
30’ 281
1374
2039
3263
551
806
2774
20o
1637
4019
20’
1037
2316
189
3520
372
544
1235
1860
3032
699
2503
10’
826
1403
10o
91
180
1993
4207
263
946
338
1516
3176
3693
402
1022
2623
Fulcrum
457
2105
494
1588
1071
517
0o
1087
1612
2138
2662
3225
3750
4275
525
Resultant
of 4:1cd

20’

10’+40’(.6)+15’(.6)(.8)

Impact Force and Fall Factor

The concept of shock absorption has always been a key factor in the world of rigging, but there seems to be substantial misconception, or at least, substantial subjective opinions on how much is too much when it comes to dropping something on a given length of fall arresting material. This question came to the surface again one day while watching a TV special on jogging injuries; according to the commentator, the average jogging step is about 7” and impact force on the knee from each step is approximately 7 to 10 time the body weight. This got us thinking; if 7” can have up to 10 times the impact force while jogging, wouldn’t the same physics be at work in rigging?

The answer is a resounding yes. However, there are factors that come into play; how stretchable is the material arresting the fall, is it dynamic rope used for lead climbing, or is it static rope typically used for belaying in rescue work? Even more important; what is the ratio between the length of the fall and the length of the belay rope in service? In other words, what is the *Fall Factor*?

The severity of a fall can by determined by an equation called the *Fall Factor*. The higher the *Fall Factor* equation, the greater the severity of the fall. The *Fall Factor* is determined by dividing the distance of a fall by the length of fall arrest material (i.e. rope, webbing, lanyards) in service between the load and the fall arrest anchor.

This, in its purest form we have labled the *Theoretical Fall Factor (TFF)*, (as we already know with other aspects of rope rigging) friction plays a major roll in the efficiency of a rope system. So too, any and all carabiners that the belay rope bends through will create more friction, and subtract from the efficiency of the belay. So too, the coefficient of friction for the belay rope going over the surface will come into play and will in essence, shorten the belay rope and rendering a higher *Fall Factor*. This should make sense than, added friction, in effect, subtracts from the length of the belay rope in service giving a higher *Fall Factor*. We call this the *Actual Fall Factor. (AFF)*

One may come to the conclusion, the higher the climber is from the belayer, and the longer the amount of belay rope is in service, the lower the risk of serious injury or death from a fall. This analogy is absolutely correct. Conversely, there are other potential hazards the climber may meet if a fall is taken closer to the top, namely, what will he/she hit on the way down before the last running anchor point grabs the fall.

As a rule of thumb, try to keep the ideal fall factor less than .5 with dynamic rope and less than .25 with static rope, serious injury may occur from a (TFF) of “1”, and death may occur from (TFF) of “2”.

Chapter 11, Elevated Anchors

Before proceeding to this chapter on elevated anchors, full comprehension of chapter 10, Force Multipliers is mandatory.

The use of elevated anchors, i.e. high directional anchor systems, is a mandatory requirement of NFPA 1670 for rope technicians. Having said this, it is impossible to discuss one facet of rope rigging and not address all the many other aspects at the same time. A rope system is like a living breathing thing; like any living thing it is composed of many cells and body parts. Yes; these many parts are separate components, but without a realization of the whole body each component means little. This is the essence of the knowledge base that rope rescue technicians must try to ascend to.

When we study elevated anchors, we are usually addressing the extremely complex subject of edge management. In other words how do we overcome edge trauma, and how to we maintain a coefficient of friction at the edge that best meets our needs? Furthermore, elevated anchors are just that…an anchor system. As with all anchor systems we must have a complete working knowledge of force vector analysis and resultant management. If this sounds like an overly demanding picture of years of advanced detailed study of an overwhelmingly complex subject…than good…we've made our point.

Safety Considerations around the Edge

When approaching an unprotected edge, such as a mountain location or an industrial site that is void of hand railings or other reliable fall protection system, the elevated anchor system needs to be belayed into place using a single tagline. Once in place, leave the tagline connected to the system and tied off at a suitable anchor as a precaution against a dynamic event. A dynamic event could include any number of things like the surface of a mountain edge falling off, or even a mainline failure. Although the system belay would arrest the load, the mainline could possibly jam the high directional pulley and radically alter the resultant causing the tri-pod to topple over the edge onto the rescue package.

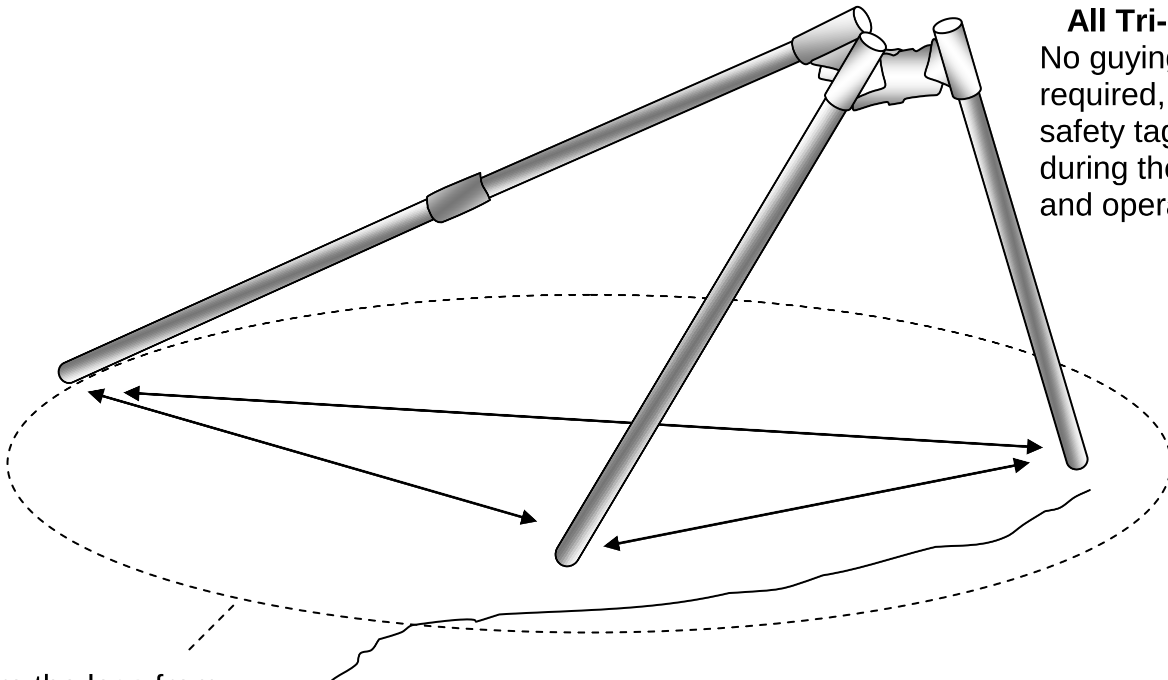
When the feet have been adequately secured to a suitable anchor, a tagline connected to the head of the tri-pod is not needed during the actual rescue operation.

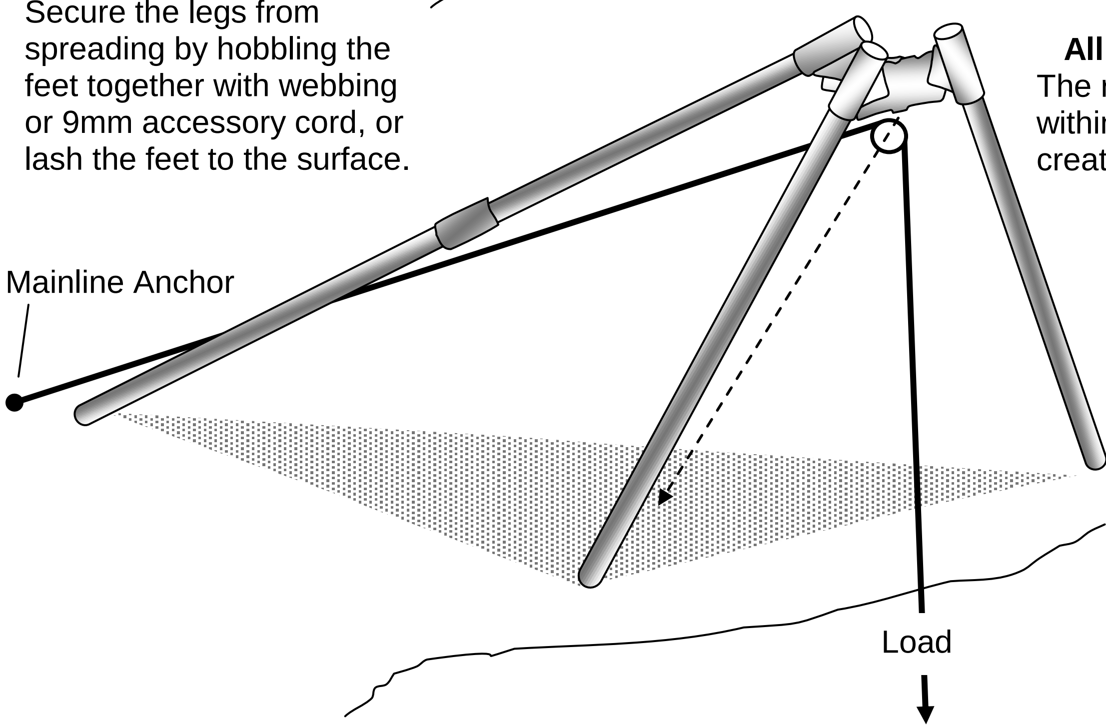
All other Multipod configurations are typically held in place by their guying system, this however, does not negate the need to belay the components during the set up and tear down process near a dangerous edge.

The system belay should never be rigged through the top of any marginal elevated anchor system. As good as today's modern manufactured elevated anchor systems are, they are still marginal anchors and are dependant on the integrity of the surface and the abilities of the riggers. Belay lines may be connected to elevated anchors that are deemed bombproof, such as a structural "I" beam, providing that the belay has a connection point on the bombproof anchor that is independent of the mainline connection.

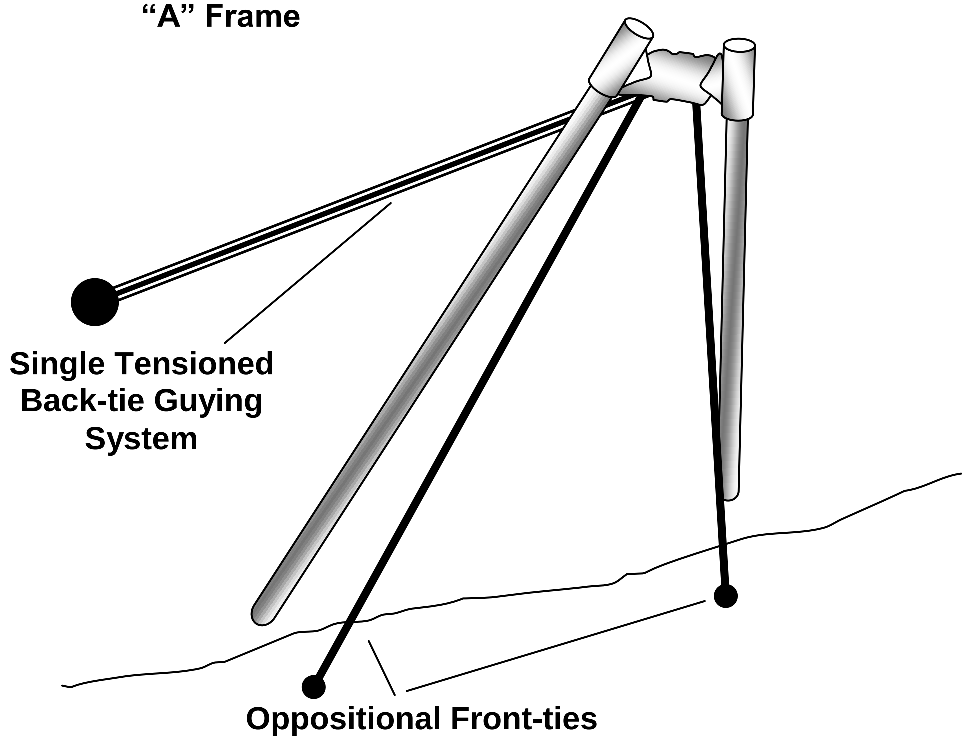
Any personnel assigned to the rigging of an elevated anchor system must be attached to an adequate travel restraint/fall arrest system while working near the edge.

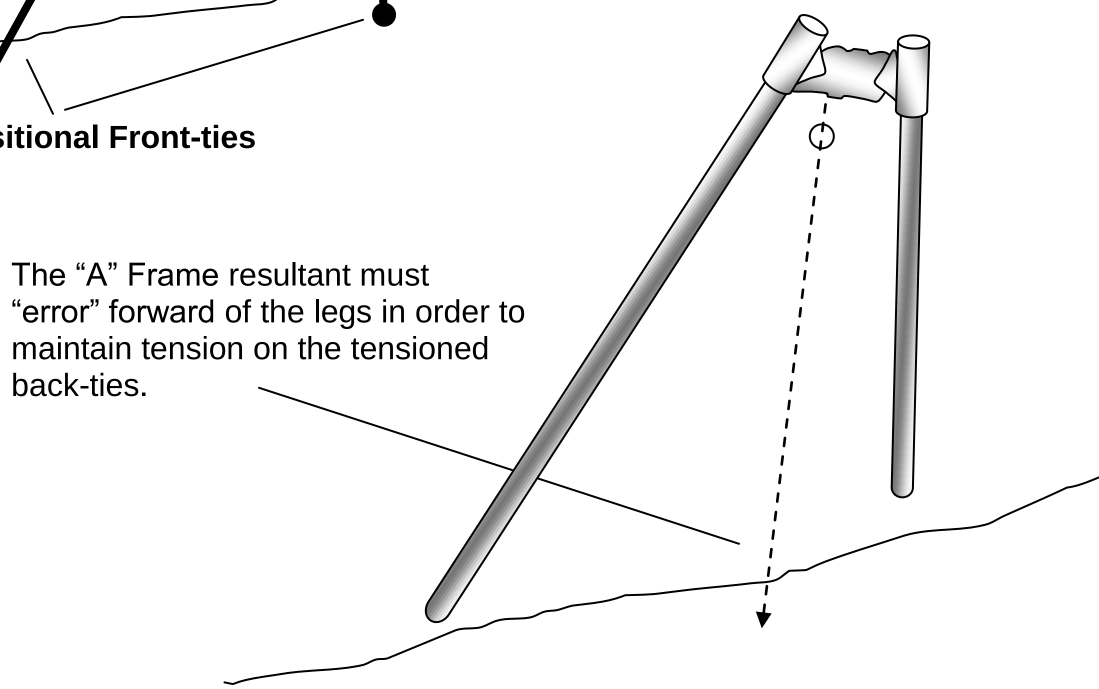
Back-tie Schematics for Elevated Anchor Guying Systems and Resultant Placement



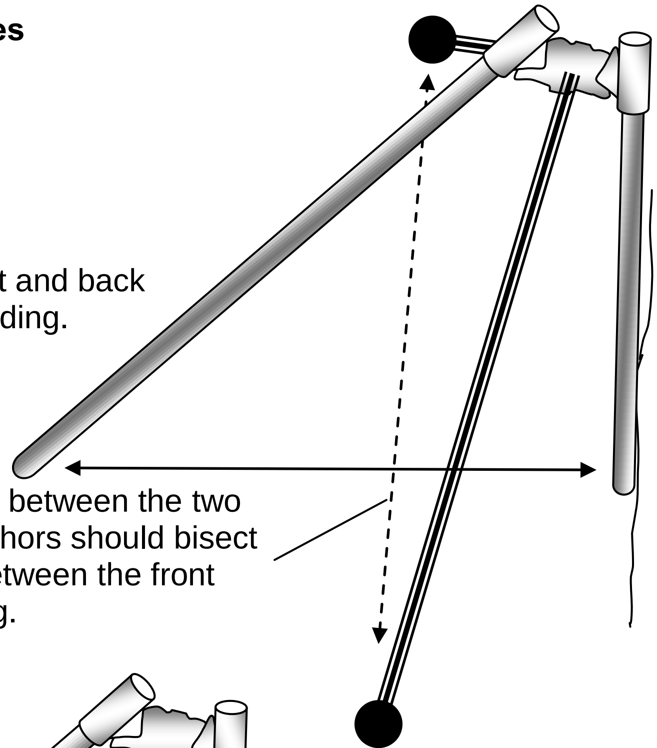


“A” Frame


Single Tensioned
Back-tie Guying
System
Oppositional Front-ties

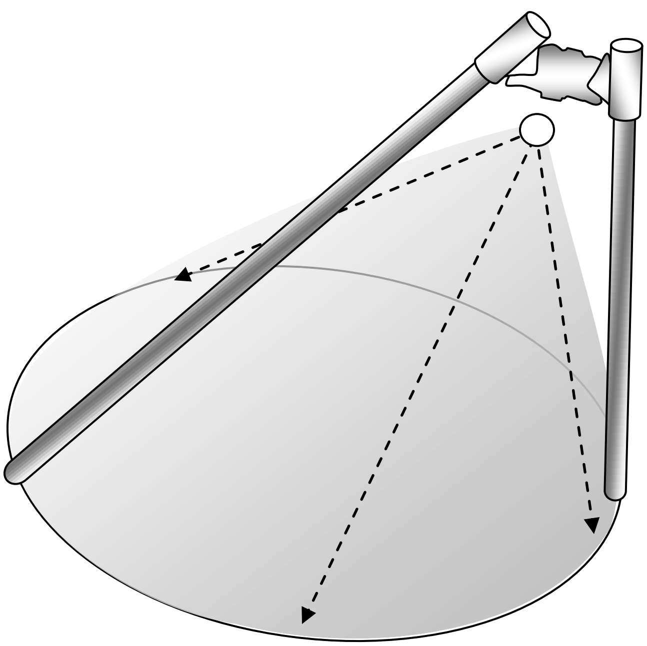

The “A” Frame resultant must
“error” forward of the legs in order to
maintain tension on the tensioned
back-ties.

Perpendicular "A" Frames



Secure the front and back legs from spreading.

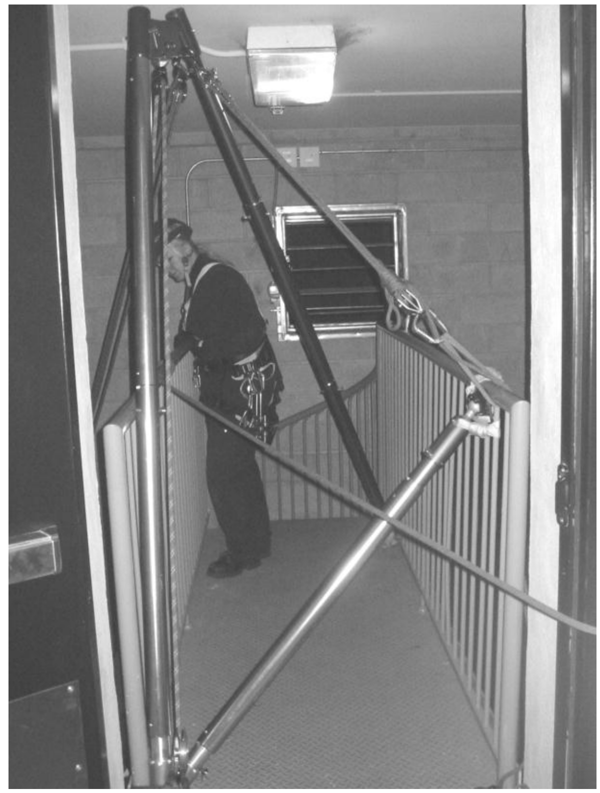
Line of sight between the two back-tie anchors should bisect the plane between the front and back leg.



The resultant has substantial latitude in virtually every direction.

The perpendicular "A" frame continued…

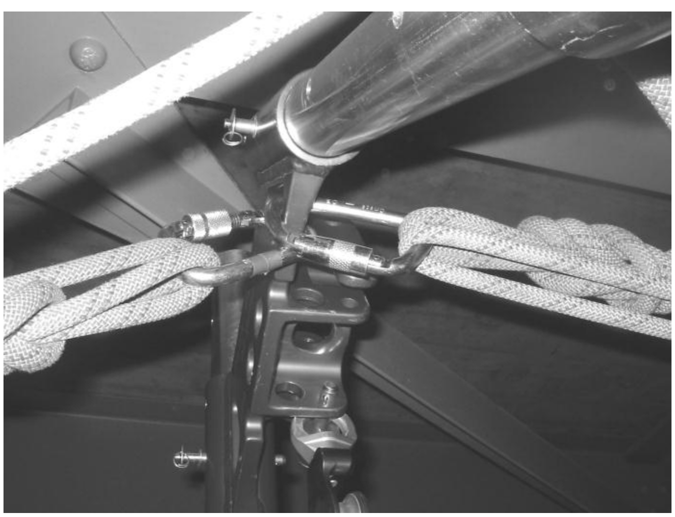
Most rope rescue personnel who experiment with all these variations of elevated anchors usually agree on one thing….the perpendicular "A" Frame is by far the safest, user-friendly, and resultant accommodating of the whole lot. Because of this, we feel compelled to talk a bit more about some additional rigging tips concerning the perpendicular "A" frame.



To the right; as seen in this photo of a challenging industrial enclosed space extrication, the perpendicular "A" frame can fit in extremely tight locations, such as industrial catwalks. The rules still apply when choosing the guying anchors for the tension back-ties. When eyeing from one back-tie anchor to the other, this visual straight edge should bisect the middle of the plane created by the front and back legs of the perpendicular "A" frame.

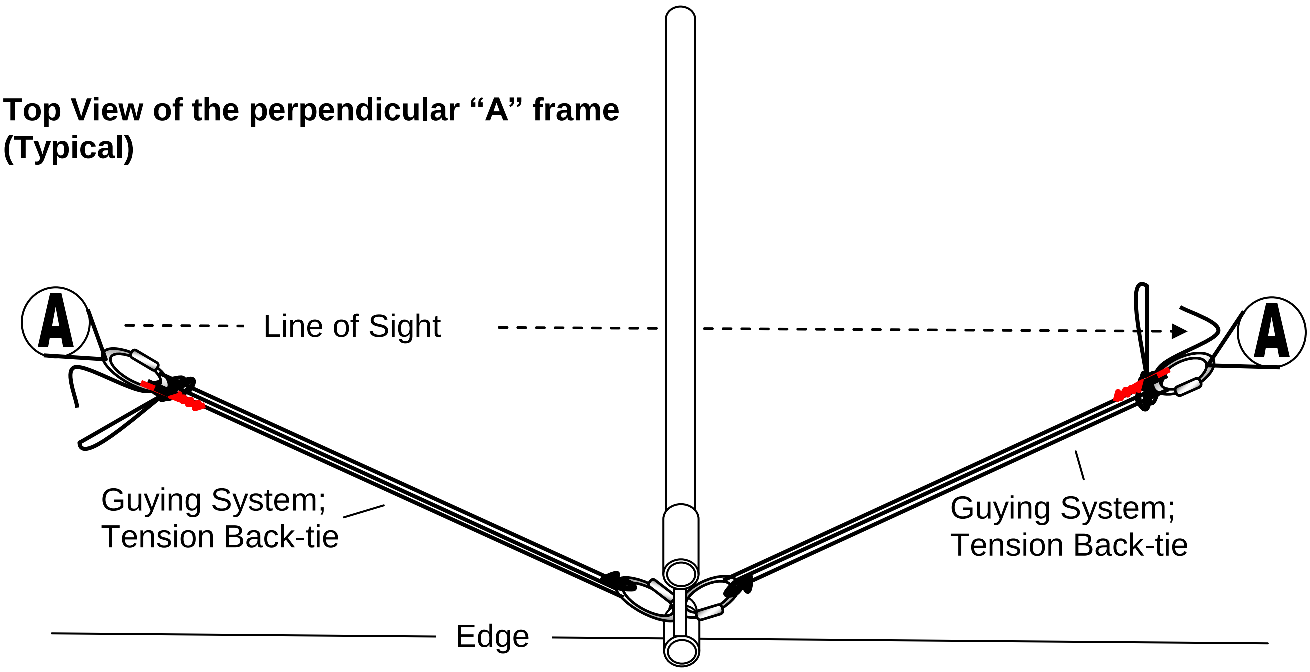
Many times when the guying/back-tie anchors don't quite line up, the perpendicular "A" frame may be rotated to make the plane of the legs accommodate the back-tie anchors.

Note the photo to the right, not only is the catwalk made usable, but an extremely wobbly hand rail is made strong by employing one unused leg of the Multipod tightly lashed to the rail as a compression member.

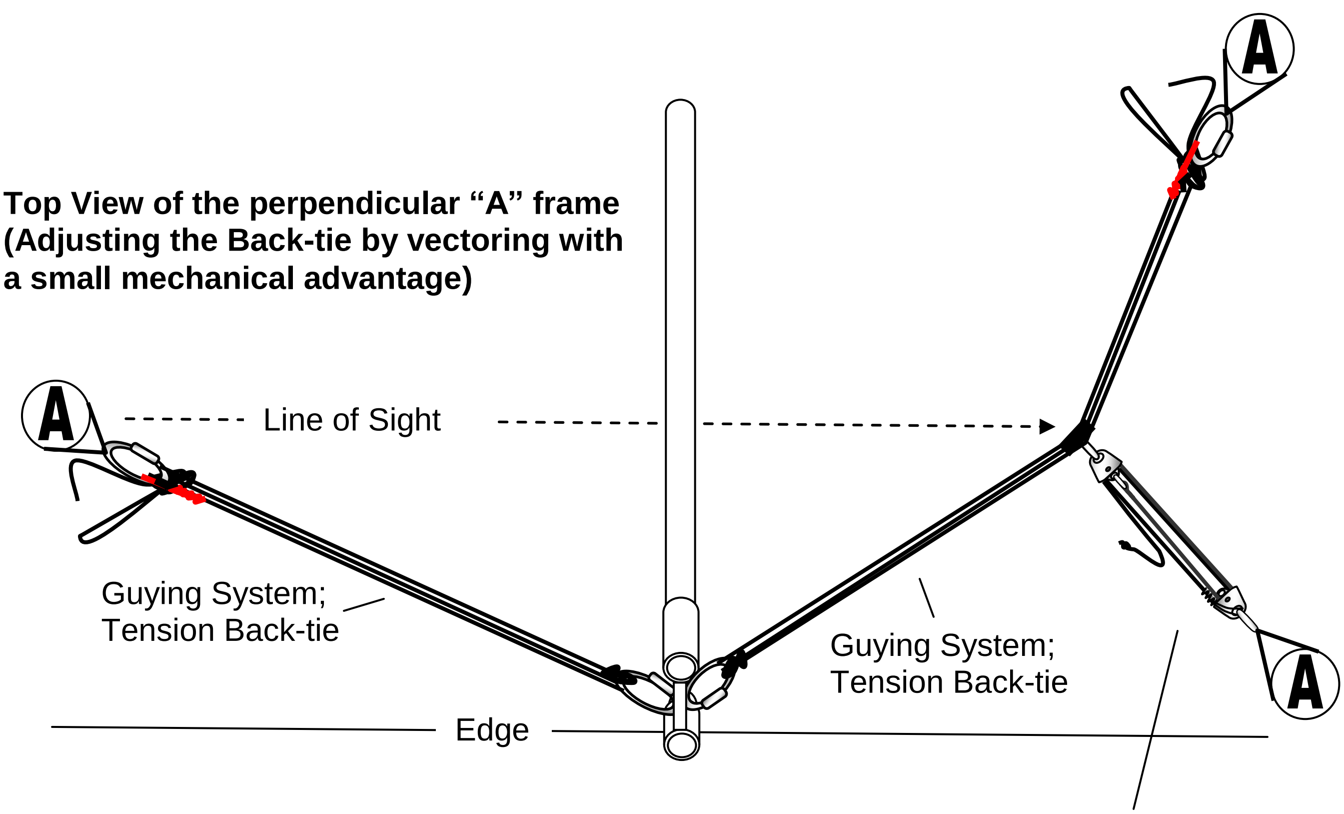


The photo to the left is a view looking up at the head of a perpendicular "A" Frame; this is a good example showing the tensioned guying system pulling opposite directions. Note that they are connected to the same location on the head; unwanted torque will arise if one back-tie is forward on the head and the opposite back-tie is rigged to the back end of the head. In addition, when more radical HD (High Directional) pulley resultants are predicted, the HD pulley should be rigged as close as possible to the same location on the head as the guying system.

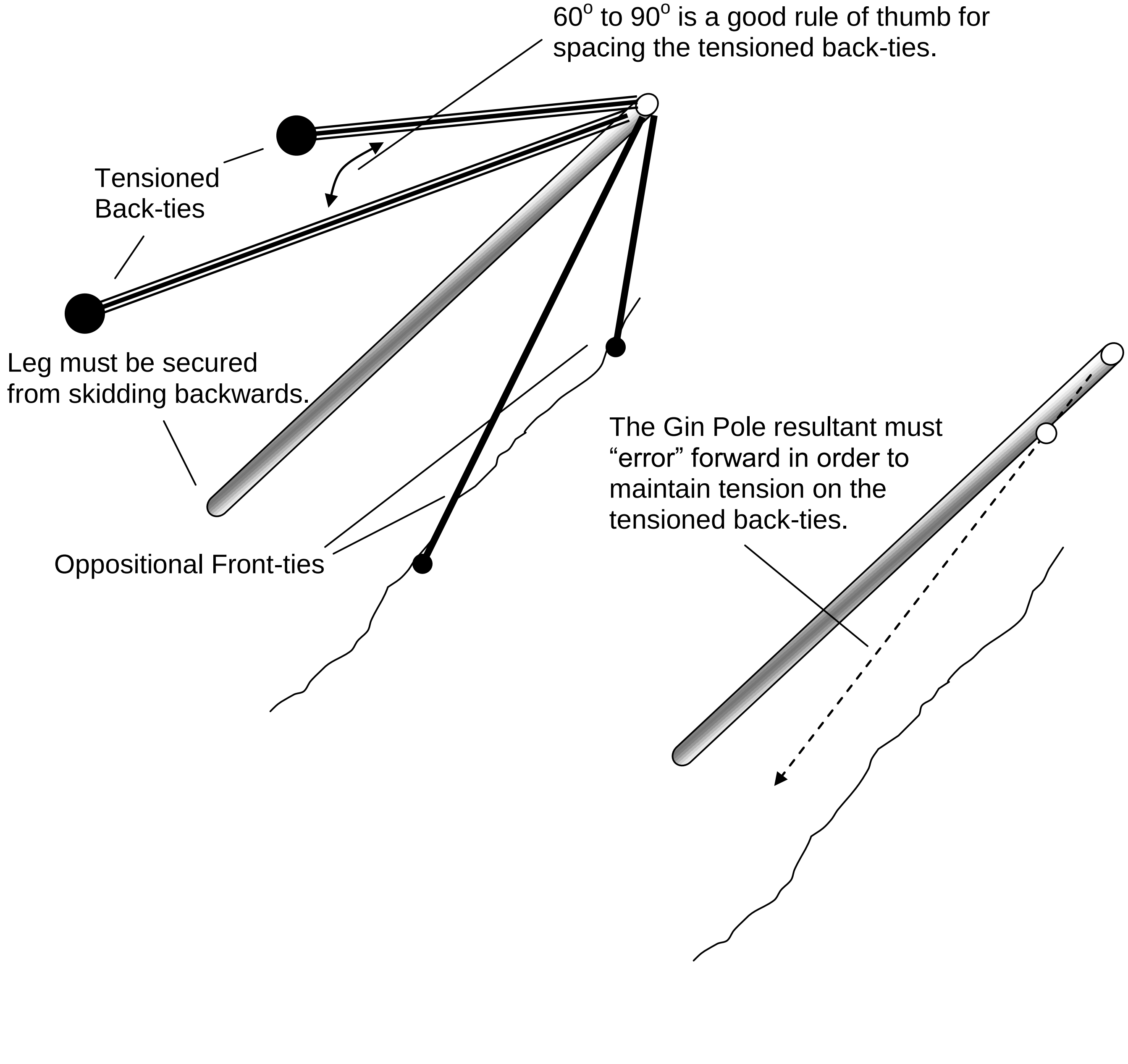
Top View of the perpendicular "A" frame (Typical)



Top View of the perpendicular "A" frame (Adjusting the Back-tie by vectoring with a small mechanical advantage)



Gin Pole


60° to 90° is a good rule of thumb for spacing the tensioned back-ties.
Tensioned Back-ties
Leg must be secured from skidding backwards.
Oppositional Front-ties
The Gin Pole resultant must "error" forward in order to maintain tension on the tensioned back-ties.

Chapter 12, Horizontal Systems

Force Vector
In general, the greater the angle between two anchor points, the greater the stress will be on those anchors. It must be the goal of the technician to minimize all angles in a manner that will still accomplish the job at hand. The kind of stress that will be required of the horizontal system is a direct relation to the distance the load must travel from the original fall line. Greater vector forces will always require more complex systems that in turn, will require a greater amount of time, and higher skilled personnel.

Horizontal Systems

In high angle rescue, horizontal systems are add-on rope systems that serve as a means to change or influence the original fall line of the mainline/belay line package. This form of rope rigging is very useful in overcoming obstacles, and correcting the horizontal orientation of the rescue operation.

We will address 3 major divisions of horizontal systems, they are:

1. Taglines
2. Dynamic Directionals
3. Highlines

These 3 may be further sub-divided into minor or major. Minor horizontal system do not require belaying from the point of horizontal influence, major horizontal system require belaying from the point of horizontal influence.

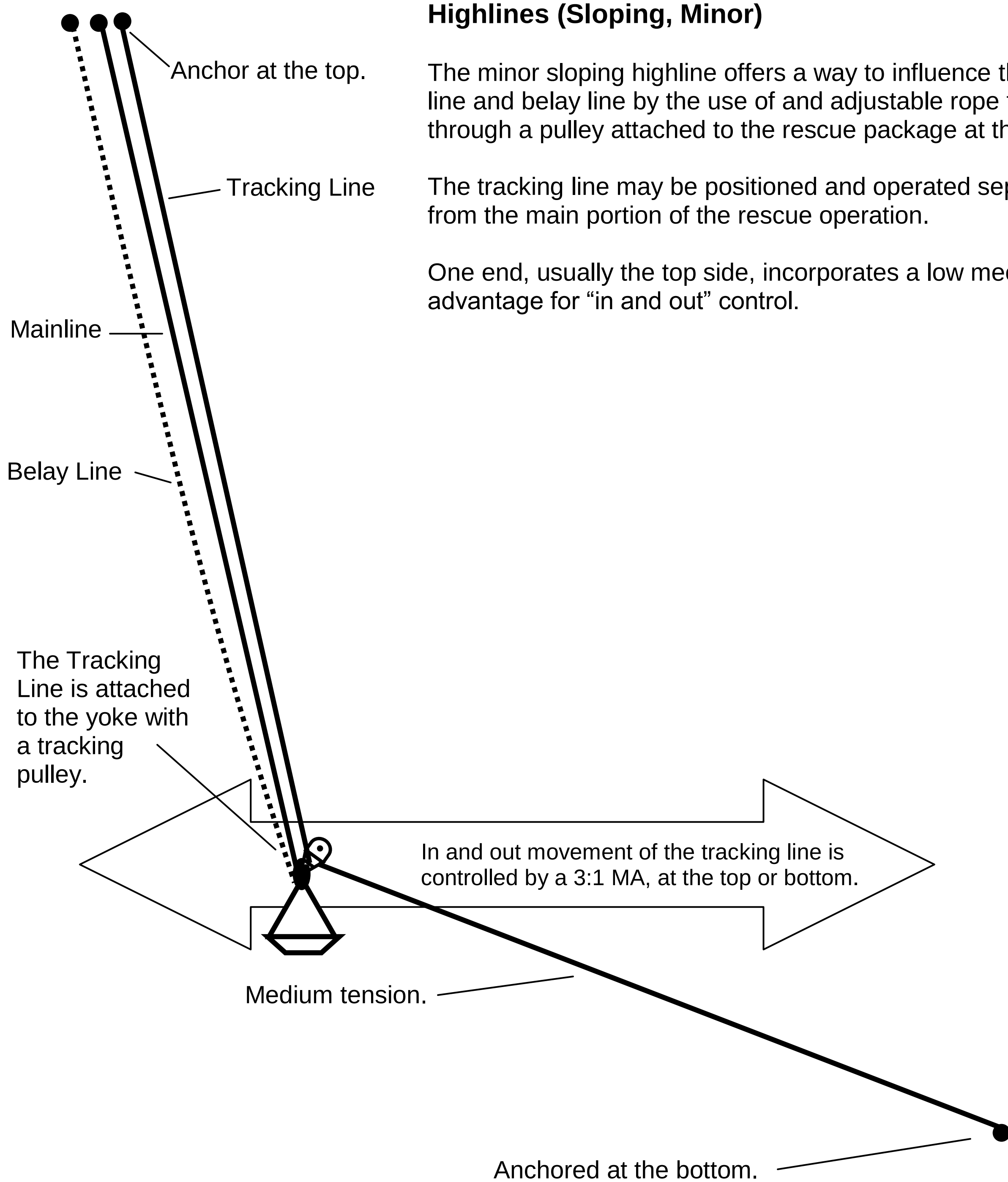
They all have advantages and disadvantages. Some work well on wide chasms, others work better on smaller gaps, some are simply used for minor adjustments of the rescue package.

Highlines (Sloping, Minor)

The minor sloping highline offers a way to influence the main line and belay line by the use of and adjustable rope that runs through a pulley attached to the rescue package at the yoke.

The tracking line may be positioned and operated separately from the main portion of the rescue operation.

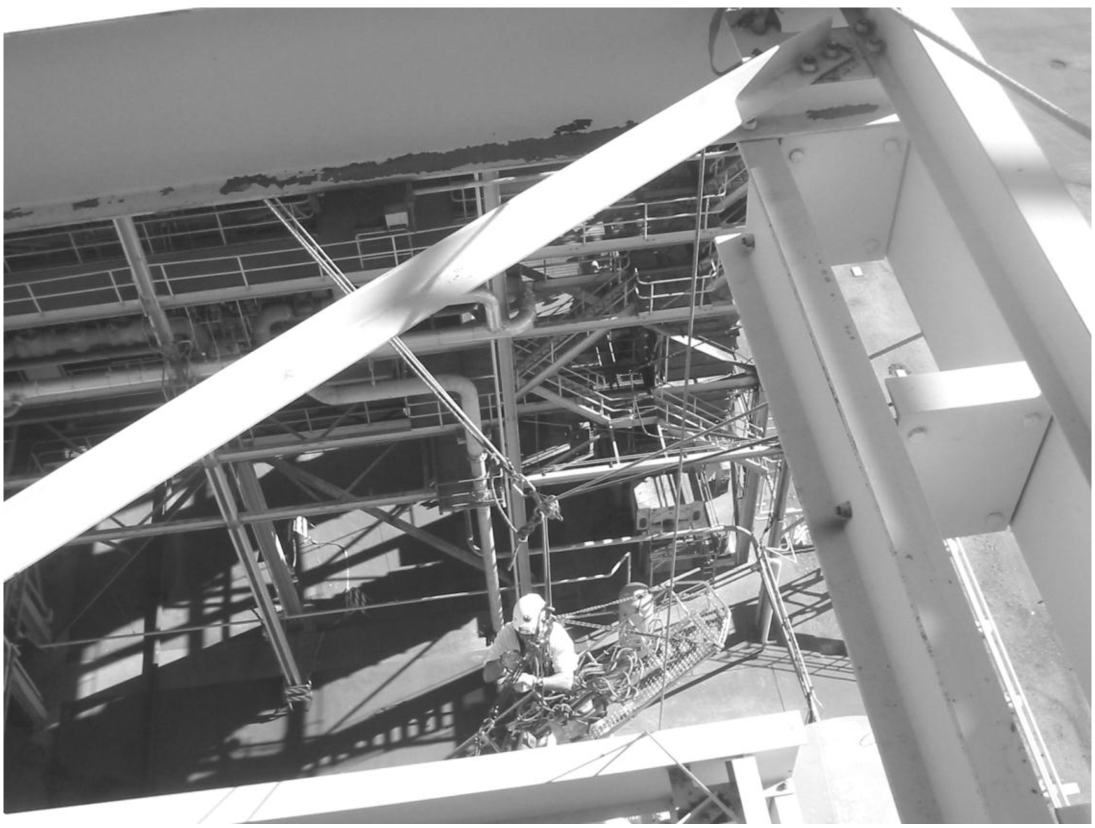
One end, usually the top side, incorporates a low mechanical advantage for “in and out” control.



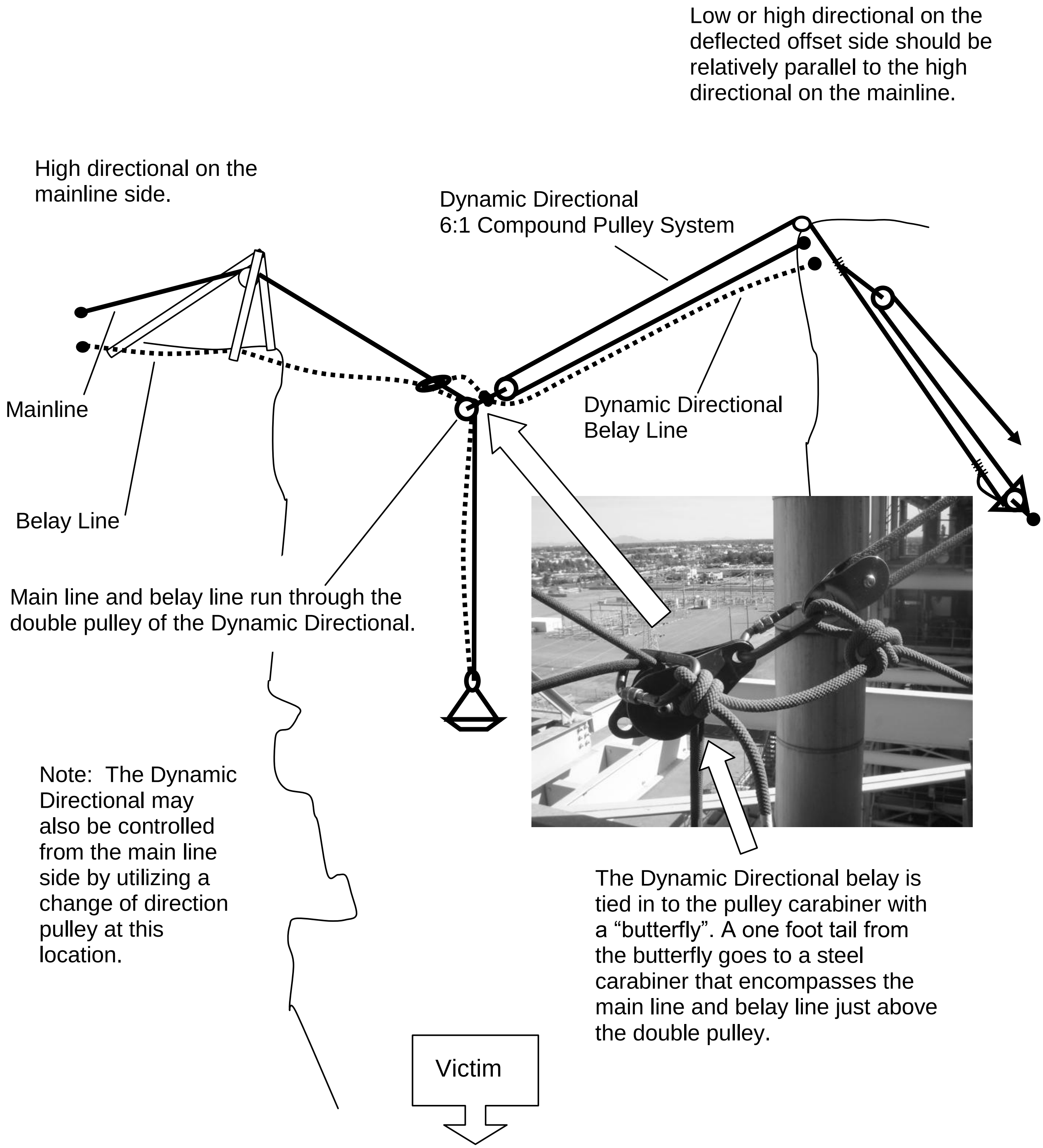
Dynamic Directional Anchors
Dynamic Directional Anchors are useful in adjusting the main line and the belay line from above the rescue package, or in some cases, from across a gap, or chasm.

The use of this system usually requires a fair amount of horsepower, at least a 6:1, and possibly a 9:1.

For short gaps, a minor dynamic directional Anchors may not require a belay for the point of horizontal influence, however the belay option may be put into use based on the decision that the dynamic directional is indeed a critical safety element of the overall operation. The key question you must ask is, if the dynamic directional were to fail, would the pendulum effect of main line cause serious injury to the rescue load?



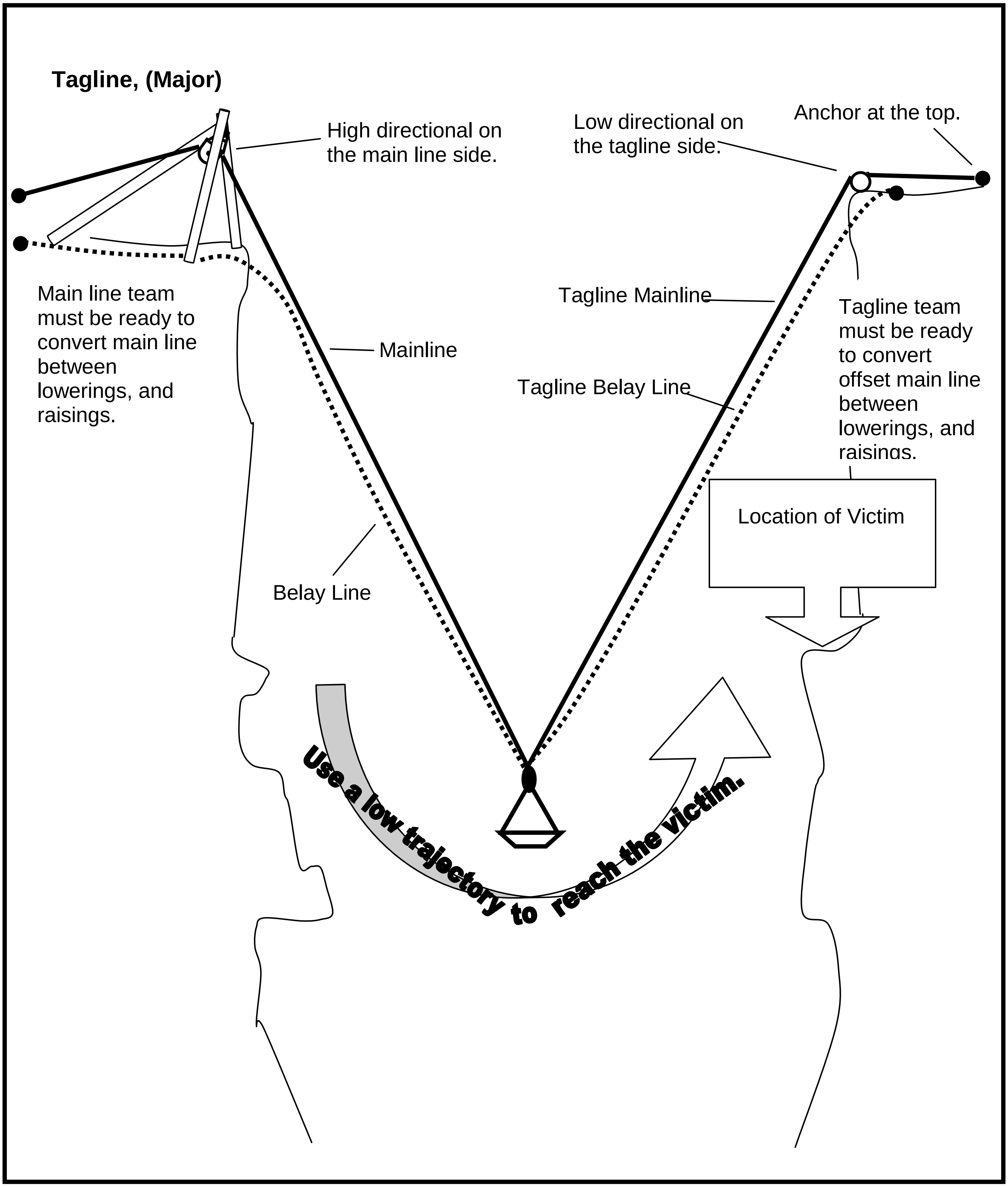
Dynamic Directional



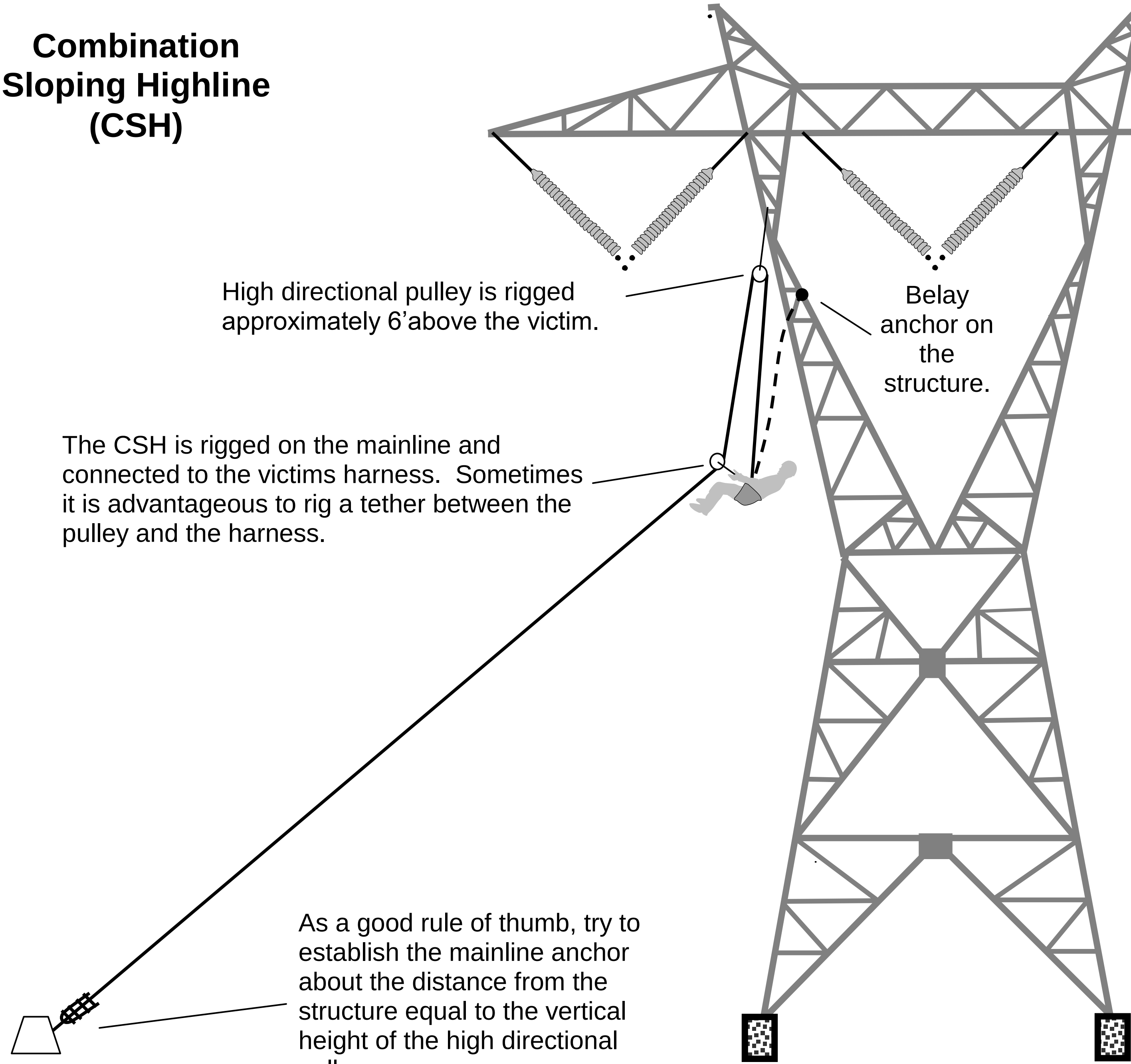
Taglines, (Major)
Major taglines employ two main line, and two belay line systems at the same time. The two working in harmony, while one is in the lower mode, the other is in the raising mode.

Major taglines are most often use to negotiate much greater gaps than the deflected offsets. In most cases the two rope offset has three distingue advantages over highline operations. It is much safer due to the two belay line systems. Anchoring is not as critical because vector forces created by the two rope offset should never approach those of highlines, and the two major tagline is much quicker to implement than highlines.

It is critical that a strong (at least 9000 pound test) multi-directional ring or tri-link be used at the apex of the two rope system. Do not use carabiners, they will side load in this application.


Tagline, (Major)
High directional on the main line side.
Low directional on the tagline side.
Anchor at the top.
Main line team must be ready to convert main line between lowerings, and raisings.
Mainline
Tagline Mainline
Tagline Belay Line
Tagline team must be ready to convert offset main line between lowerings, and raisings.
Location of Victim
Belay Line
Use a low trajectory to reach the victim.

Combination Sloping Highline (CSH)



The CSH is extremely useful for extrications from structural towers, industrial settings, and even tree rescues. This offset is easy to rig, and control excessive tension. The victim should gently touch down several feet in front of the mainline anchor.

Highlines

Highline operations are one of the most dangerous and most difficult vertical rescues. Highline rescues invoke the use of advanced rigging skills, performed by advanced technicians. Under no circumstances should a highline be attempted solely on the instruction of this book. Anyone interested in performing a highline must have intermediate skills, and seek advanced training through an accredited school of rope rescue. This section of this chapter gives only a general overview of this extremely complex subject of highlines. For a fuller understanding of highlines RescueRig offers rigging courses for advanced level technicians.

99% of the time, most high angle rescues can be accomplished through the use of helicopters, and/or a mainline/belay line system combined with various forms of offsets. It is that rare 1% of the time that a highline might be needed. Typically, highlines are incorporated where a long expanse or swiftwater must be negotiated for the successful extrication of the victim.

Highlines are almost always a last resort option. The good side of highlines is that it is a viable option; the bad side is that there are numerous reasons why not to do one. If over tensioning and rope abrasion are the archenemies of rope rescue operations, than consider these two evils the devil incarnate to a highline.

By its very nature, highlines go against most conventional rules of safe anchor building. In most cases, we try to keep the angle between multi-point anchors 90% or less, at 120 degrees the force at each anchor equals the weight of the load. With highlines, you are looking at a vector angle of 150 degrees and up. This alone will multiply (with the rescue load in the middle of the trackline) the weight of the load anywhere from 2 times at 150 degrees to 11 times at 175 degrees at each anchor!

Because of this tremendous stress highlines put on the anchors, here are some key principles that must be included in the construction of highlines:

- Anchors must be bombproof.
- Full strength of the trackline must be utilized by eliminating all knots, and all sharp bends.
- All knots on the control lines must be bypassed.
- Maintaining a pulley tension system to the highlines utilizing a “slipping clutch” (or safety fuse) in the form of system prusiks. (8mm, 3-wrap)
- Incorporate a carriage system supporting the load.

As with any rope rescue operation, highlines even more so, must be able to pass the “whistle test” and the “critical point test”.

Whistle Test

What would happen to the system and/or the rescue party if anyone, at any station within the system, failed to perform their respective job, or, suddenly left their station for some reason?

Critical Point Test

If any point or points in the entire system were to fail, would it lead to the catastrophic chain reaction failure of the entire system?

Highline Definitions

Highline: A tensioned horizontal or diagonal rope system drawn tightly across a gap to assist the access of rescuers, patient and/or equipment.

Extreme Highline: A horizontal/highline system typically over 300 feet in length.

Control Lines: Ropes rigged on both ends of a highline used to control the movement of the carriage system.

Chord: The straight-line distance from side to side.

Control Line Hangers: Tagline hangers are loops approximately 2' long, typically tied from 6mm cordage. These loops are used to support the taglines on longer tagline systems usually over 150' in length. The hangers are affixed to the trackline via a carabiner, and to the taglines using a girth hitch. Tagline hangers should be placed approximately 75' to 100' apart.

Vector Angle: The angle of the trackline (chord), typically when the load is in the middle of the system at the point of greatest stress.

Deflection: Deflection is the sag of the load creating the vector angle typically represented as a percentage of the length of the chord, i.e. a single rope trackline 300' long should deflect approximately 10% or 30' when the load is in the middle of the system.

Carriage: A carriage is the traveling support system for the load typically rigged with pulleys.

Pilot Line: The pilot line is the very small first line, usually nylon "masonry line cord", light enough to spool from a line gun or throw across the gap.

Messenger Cord: The messenger chord is the second line light enough to be pulled across by the pilot line yet strong enough to pull the larger tagline rope across without breaking, typically a 3mm cord.

Stages of Highline Operations

Highline operations consist of five major stages, they are:

- Spanning the Gap
- Construction of the high directionals
- Construction and Tensioning of the Trackline
- Construction of the tagline/belay systems
- Construction of the carriage
- Break down.

Spanning the Gap

As stated earlier, the initial action of a highline operation is getting the various ropes across the expanse. Typically the order of lines used is; the pilot line which pulls the messenger line which pulls the opposite side tagline.

There are a number of ways to get the pilot line across, including something as simple as a hand thrown weighted object with the pilot line attached.. To negotiate a long horizontal expanse, a more sophisticated delivery system must be deployed, namely the use of a cross bow, a line gun or a rocket delivery system.

The messenger cord is the second line pulled into place by the pilot line. Providing the messenger cord is twice the length of the expanse, it may become very useful as a means to transport various equipment back and forth between sides.

The messenger cord in turn pulls the first ½ inch system rope across, usually the opposite side tagline.

The opposite side tagline will pull the trackline, the carriage end of the "control" side tagline, and a pulley.

Once the trackline is secured at both ends, the pulley will allow the control side to bring the carriage ends of both tag lines back to the control side for completion of the carriage system.

Construction and Tensioning of the Highline

There are immense forces generated at each end the highline, because of this it is imperative that all knots be eliminated from the highline, and that the highline not be over tensioned.

The highline must be one continuous rope and the opposite side must be anchored with a high strength tie-off.

The control side of the highline is *typically* finished off with an integral 3:1 MA. (Ganged systems are sometimes used, especially for bundled 2 and 4 rope highline systems.) This MA should include tandem prusiks at the ratchet pulley (This is the only time tandem prusiks should be incorporated in a mechanical advantage.)
When pre-tensioning the highline, use only one person to pull on the equivalent of a 3:1 MA. Post tensioning of the highline the maximum number of haulers is dependent on the weight of the rescue load, the length of the highline, and the amount of desired percentage of sag.

Multiple Bundle Highlines/2 Rope, and 4 Rope Highlines

As stated earlier, one of the most critical points of a highline operation is the amount of tension at each anchor created by the vector force of the load. In pre-tensioning a single highline we would use a single person pulling on the 3:1 MA, this would allow for approximately a 10% sag with the load at the middle.

There may situations that will not allow for this much sag i.e., swiftwater highline rescues. For these types of highlines where little sag is wanted, it would be very dangerous trying to remove the sag by increasing the tension. This problem is solved by the deployment of additional highline, also known as bundles.

Typically seen are 2 rope, and 4 rope highline. Keep in mind, that the sag is lessened by the addition of more highline to the bundle, the tension on each individual rope in the bundle is still going to be about the same.

Highline, Floating “A” Frame

The use of high directionals is a very important aspect in the construction of highlines, especially on the side the rescue package will be brought to.

The first option would be for a “natural” high directional, usually a tree, if this is not possible, the “A” frame makes a quick an easy to set-up alternative.

When used in this application, the “A” frame does not need to be guyed in the traditional manner as shown in chapter 5. After the trackline is constructed, lash the “A” frame together, hook a pulley to the trackline and connect it to the apex of the “A” frame while the “A” frame assembly is flat on the ground. The “A” frame can easily be vectored into place prior to the pre-tensioning of the trackline.

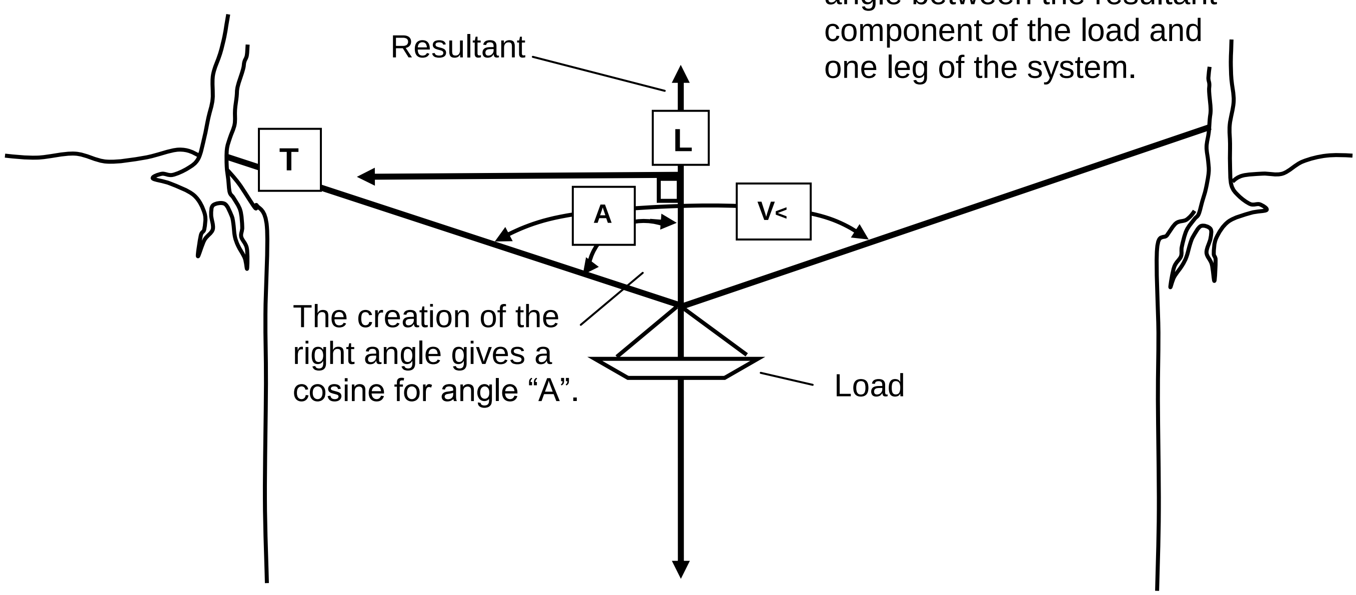
Once the “A” frame is upright, it is then guyed into place by employing two opposing system prusiks connected to the trackline on both sides of the pulley.

Floating “A” Frame on a twin trackline; note the prusiks front and back on the trackline facilitating the guying of the high directional.

Highline Tension Formula

$$T = \frac{\frac{L}{2}}{\cos A}$$

Looking at ½ of the entire system we can derive the amount of tension at one anchor by creating a right angle between the resultant component of the load and one leg of the system.

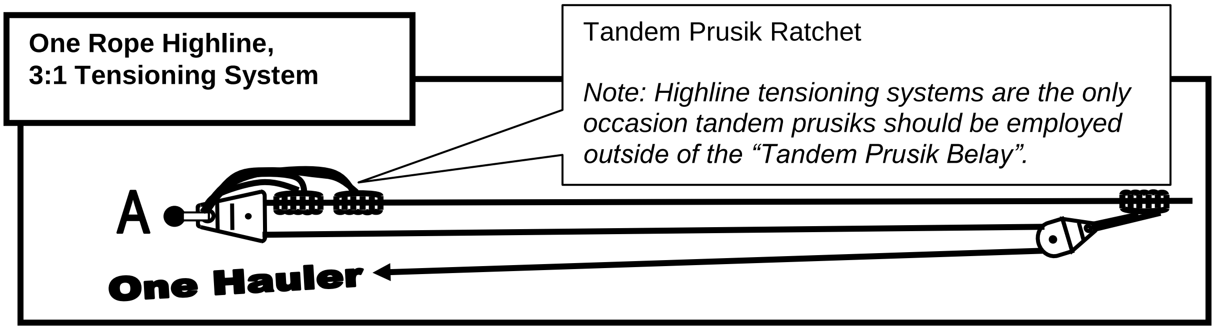


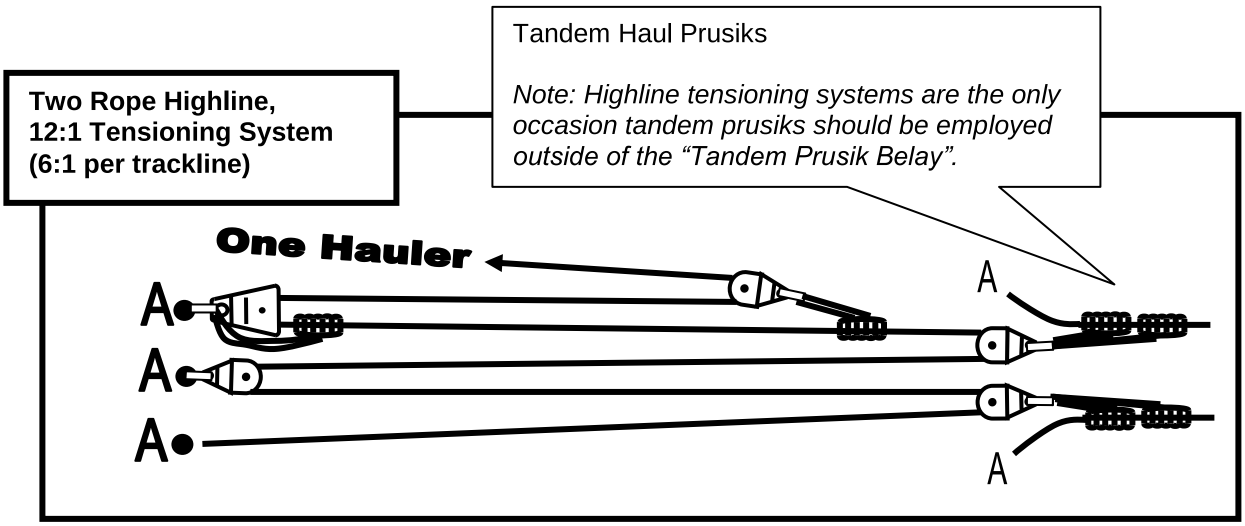
Second Option

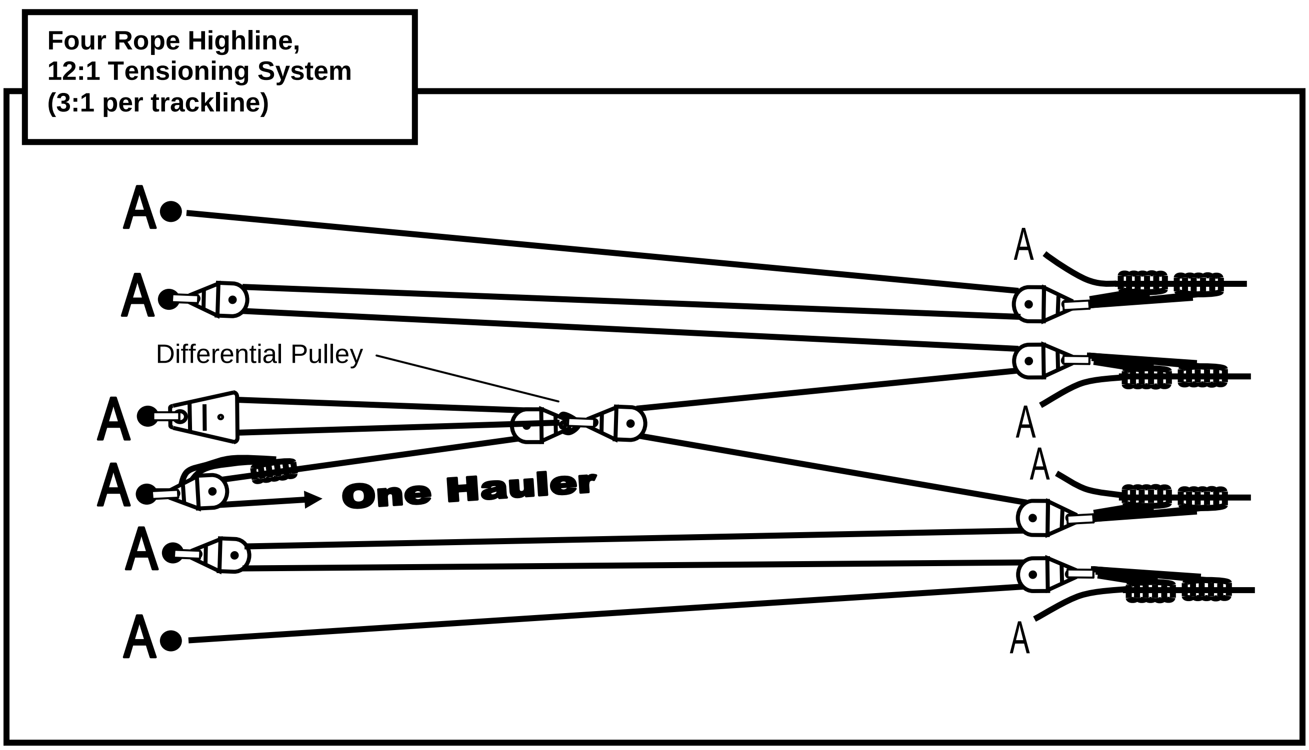
Based on cable yarding calculations from the Cable Yarding Handbook, Work Safe BC

$$\frac{(\text{Load})(\text{Span}_{\textit{in feet}})}{(4)(\text{Deflection}_{\textit{in feet}})}$$

Highline Pre-Tensioning Systems







Chapter 13, Mid-Wall Rescues

Mid-wall rescues can run the full gamut of rescue complexities. It can include almost everything from one or two people coming to the rescue of a fellow climber, to a fully orchestrated team-based rescue. Because of this we have divided pick-offs into two major division's 1) Solo Rescue, and 2) Team Based. These two divisions can be further subdivided A) Clinging, and B) Hanging, depending if the victim was simply free climbing, or if the victim was using a harness and rope.

Solo Rescue
Solo rescues are rappel operations, which needs two rescuers from start to finish. One rescuer will rappel to the victim and perform the pick-off, and the second rescuer will stay topside and belay.

Team Based
A team-based rescue is done with a system lowering. It is designed for three or more team members and because it is a lowering (not a rappel) the attendant's hands are free for a quicker capture of the victim. This type of pick-off will also allow for the option of a system raising should the need arise.

	Clinging	Hanging
Solo Rescue	***Rescuer Is On Rappel*** • Fastest, but greater risk. • Two rescuers are required. • A harness must be placed on the victim. • Rescuer rappels with a system brake rack. • Must employ a tandem prusik belay or equivalent (two person load).	***Rescuer Is On Rappel*** • Fastest, but greater risk. • Two rescuers are required. • Transfer must be made from the victim's system to the rescue system. • The victim's harness may be used if it is deemed safe. • Rescuer rappels with a system brake rack. • Must employ a tandem prusik belay.
Team Based	***Rescuer Is On the System*** • Safest, but more time and equipment is needed. • Must have at least three rescuers. • Rescuer is lowered and/or raised with system. • A harness must be placed on the victim. • The rescuer has the full use of his/her's hands..	***Rescuer Is On the System*** • Safest, but more time and equipment is needed. • Must have at least three rescuers. • Rescuer is lowered and/or raised with system. • The victim's harness may be used if it is deemed safe. • Team may convert to a raise to facilitate un-weighting the victim from his/hers system. The rescuer has the full use of his/her's hands.

Clinging rescues of the Non-Injured or Slightly Injured Victim
An unsupported pick-off is rescuing a climber or hiker from a vertical hazard. This person has no harness; rope or any other fall arrest system, and is almost always inexperienced.

Because of this person's inexperience and probable fear, the rescuer should be prepared to capture the victim as quickly as possible. This can be best accomplished by using a pick-off harness, and having it and all other pick-off equipment pre-rigged before the rescuer's descent to the victim.

The rescuer should be talking to the victim as soon as possible, offering assurance of safety, and explaining what will take place. Do not make any sudden or hard pulls or jerks on the victim. Remember, this person is deathly afraid of falling, and not unlike a drowning person, he may see you as the life preserver---something that will keep him from going down. Reassurance, confidence, and professionalism are paramount in keeping this victim calm.

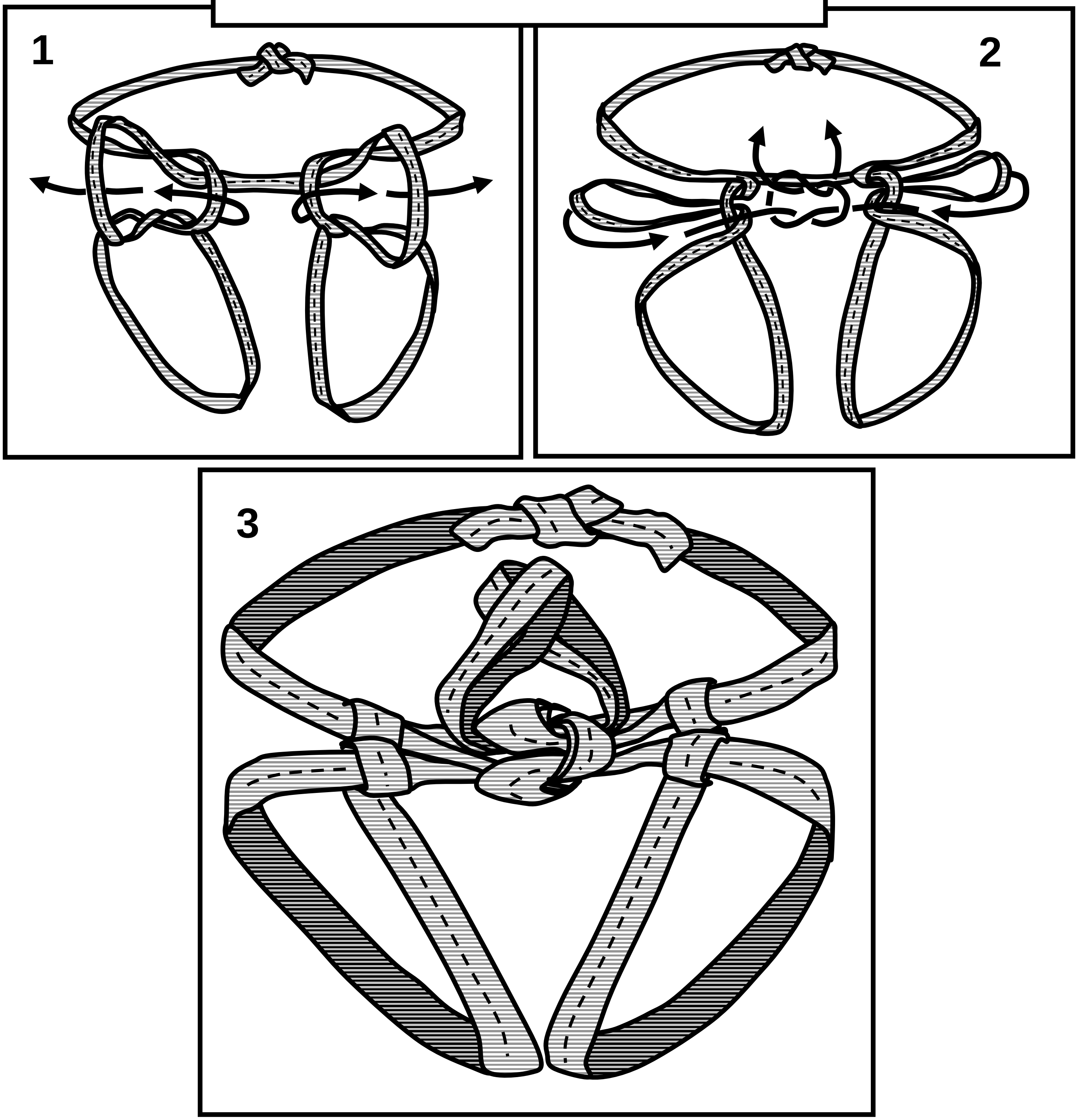
Pick-Off Harness Made From Webbing, (The Diaper Sling)
There are numerous victim harnesses on the market that are very good. A great deal of efficiency may be afforded to the rescue process as a whole when these manufactured harnesses are used in accordance to the recommendations of the manufacture. We will not explore these various manufactured harnesses, instead, let's play as if we only have webbing to fashion a victim's harness. This concept is also consistent with our general theme of this book in that rescuers should think light and that most rescues should be completed with the equipment typically carried on their own rescue harness "Rescue from the hip". When manufactured rescue harnesses are available they should be used, but consider a diaper sling made with a 15' piece of webbing as a viable back-up to the manufactured versions.

For most adults, the diaper sling is best made using 15' of webbing. Tie the webbing into one large loop using a "Overhand Follow Through Bend" (Water Knot). This loop may be draped over the victim's shoulders from the backside (keep the water knot of the loop next to the victim's neck). The rescuer should then reach through, between the loop and each side of the victim's body, with both hands reach down and in front of the victim's legs and grab the bottom of the loop. Care should be given pulling the bottom of the loop up between the legs, and back out and around the side of the victim. The rescuer can finish the "diaper sling" by dressing all loose ends of the webbing, bringing the ends around and to the front of the victim's waist, and tying a square knot.

After a pick-off strap and the belay line have secured the victim, the rescuer may choose to secure the chest and shoulder by tying a 12" to 15' webbing loop. The webbing should be pre-tied into a loop using an "Overhand Follow Through Bend". This loop can then be tied to the victim with a "Double Girth Hitch" around the chest, and slipping one of the top sections of webbing over one shoulder. The remaining tail of the chest loop should be tied to the diaper sling.

Note: On smaller body sizes excess webbing (prior to putting the finishing knot and carabiner on), should be wrapped either around itself, or around the victim's waist. The final tail should not be over 6" to 8" in length.

Unsupported Pick-Off, Diaper Sling Schematic



Hanging Pick-Offs of the Non-Injured or Slightly Injured Victim

A hanging pick-off is the rescue of a victim who is still on rope. That is to say he is in a harness, or he has some form of support from a fall arrest system.

Any number of things can cause a person to become stuck on a rope. The great majority of the time it involves a jammed rappel device. The rappel device is usually fouled by the victim's own hair or some bulky article of clothing. Once again, because this person was unable to perform a "self rescue", he probably lacks experience, and you can count on him being scared.

Because this victim is supported, you do have time on your side, and if resources are available, a ***Team Based*** pick-off should be the first option. Any serious injuries to the victim, especially any kind of neurological compromise, a more involved rescue utilizing a litter for the patient adjunct must be performed.

Evaluate the victim's rappel line. What is the quality of the anchor, and the victim's rope? The victim may want to rappel down on his own system after being freed from the jammed rappel device*, we strongly advice against this.* This person is probably in a "shaky" state of mind in the first place, and once the rescuer assumes control, it is the responsibility of rescuer to maintain control until the victim is safely on the ground.

Once contact has been made with the victim, and the rescue connections have been made (the pick-off strap, and one of the long tails from the "Double Long Tail Bowline"), the victim must be taken off of his system. When all else fails, and the need to cut the victim's rope is deemed necessary, boot scissors are one of the best tools for this job. An open knife is extremely hazardous around tensioned rope, especially if the knife accidentally touches any part of the rescuer's support system.

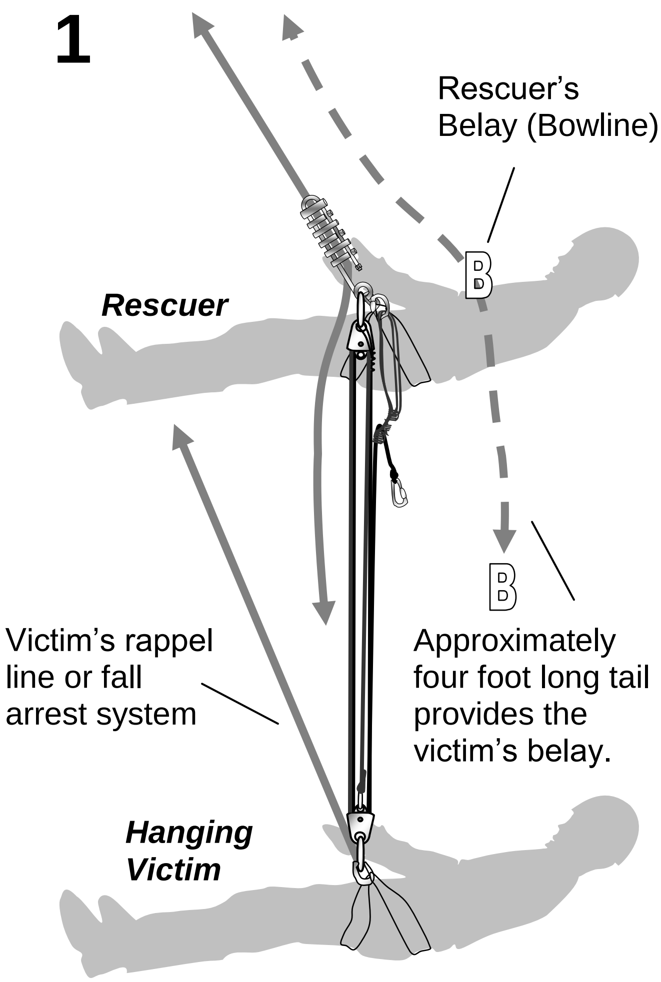
To remove the victim from his rope, his weight must be raised off of his rappel device by using a mechanical advantage.

For a ***Team Based*** pick-off, the MA is rigged at the top by the team, usually a ganged-on system is needed to be raise the load. Once the victim has been freed the team based MA lowers the victim onto the pick-off strap.

For a ***Solo Rescue*** pick-off, This MA must be rigged by the rescuer. There are a number of ways to use this tool, we prefer to use two "double mini-PMP pulleys" and utilizing this pulley system not only to un-weight the victim from his/her's system, but also allow it to double as the primary attachment to the victim.

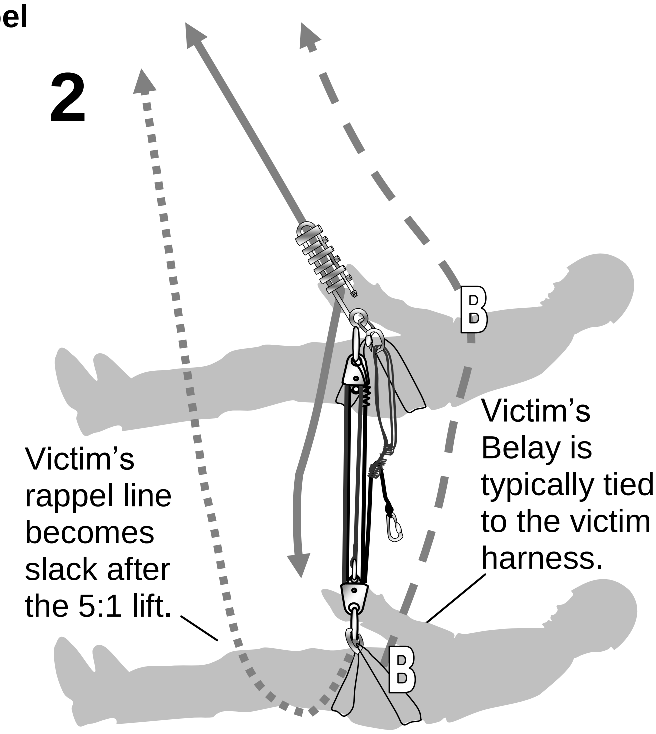
With all this in mind, the single tool I most prefer when in comes to mid-wall rescues is the edge kit that is profiled in the previous chapter. With a pre-rigged 5:1 conveniently packed into the edge kit, a speedy but safe operation is greatly enhanced; remember *Rescue from the hip!*

Solo Mid-wall Pickoffs, *Hanging Victim*
Utilizes a Mini 5:1 and a Brake Rack on Rappel



Step 1 – Rescuer pre-rigs the mini 5:1 for maximum length. The ratchet prusik and haul end (shock absorber) must be accessible to the rescuer at all times. The lengthened mini 5:1 is typically draped over the rescuer's shoulder during his/her rappel.

Step 2 – Rescuer stops approximately 5 to 7 feet from the victim, ties off the descent device, hands the victim's end of the mini 5:1 to the victim and closely monitors the victim's self-connection. For a victim that is unable to assist, the rescuer must be prepared to invert to make an unassisted victim connection.



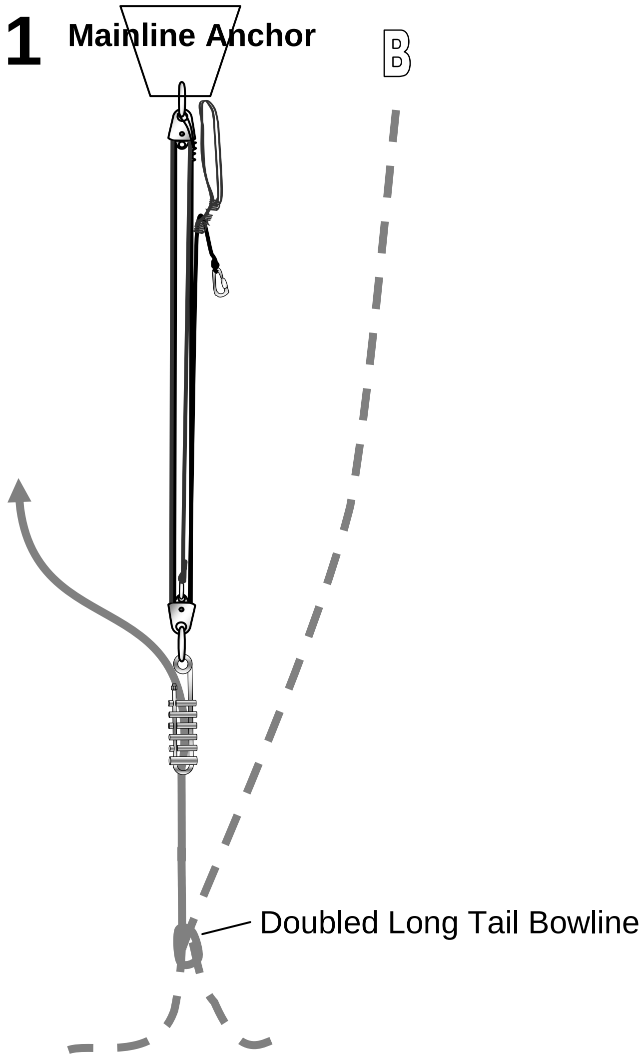
Step 3 – Using the 5:1 MA, the rescuer hauls the victim up until the victim's rappel line becomes slack and the rescue belay line can be attached to the victim.

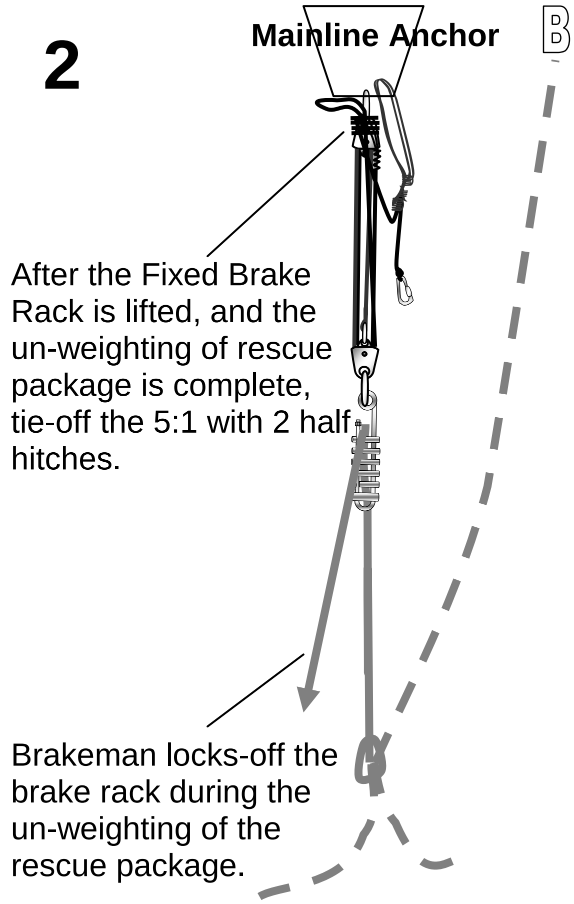
Step 4 – The rescuer ties off the MA/victim's primary attachment, connects the victim's belay, detaches the victim's rappel line and descends to safety.

Belay Line Connections

Belay line is attached to the rescuer by employing a bowline with a four foot tail to the chest "D" ring of the rescuer's class III harness. The long tail of the bowline is used to tie the end of the belay line to the victim. A bowline is the perfect knot for the rescuer's attachment point because it facilitates the adjustment of the slack between the two parties without disconnecting it from the rescuer.

Team-based Mid-wall Pickoffs, *Hanging Victim*
Utilizes a *Fixed* Mini 5:1 and a *Fixed* Brake Rack*





Mainline and Belay line Operations

Step 1 – Rig the Fixed Brake Rack to a fully extended mini 5:1 which is rigged to the mainline anchor.

Step 2 – Rig a system belay (i.e. tandem prusiks).

Step 3 – Rig a Doubled Long Tail Bowline to the rescue end of the mainline and belay line, and connect the rescuer's harness waist "D" ring to the Doubled Long Tail Bowline. Tie one of the long tails of the bowline a second point of attachment on the rescuer's harness.

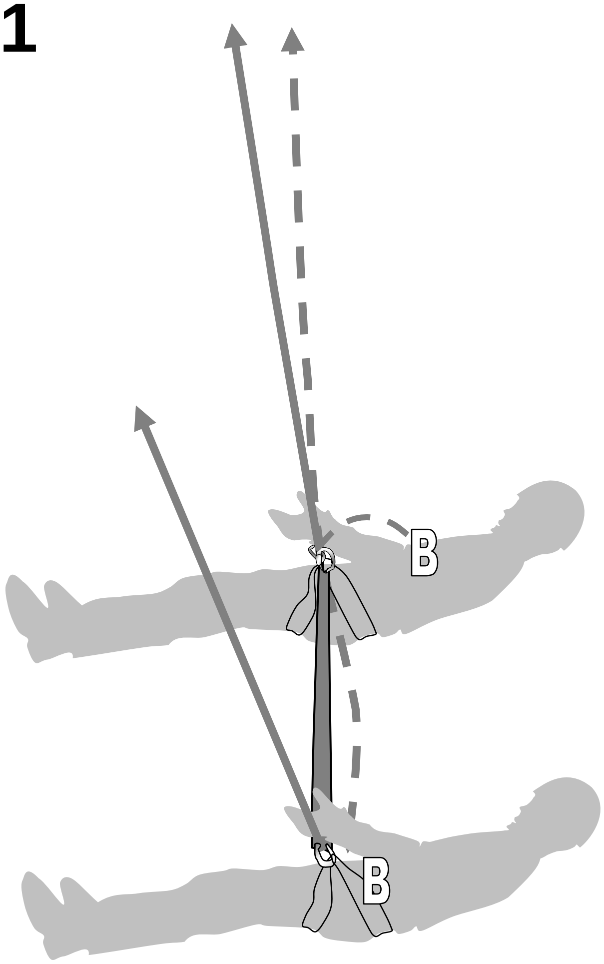
Step 4 – After the rescuer has reached the victim, and the victim connections have been made, (see next page) the victim's rappel line must be un-weighted by hauling the locked off Fixed Brake Rack using the 5:1.

Step 5 – Once the victim's rappel line is un-weighted, tie-off the 5:1 with two half-hitches and resume the lowering with the Fixed Brake Rack.

**Fixed Mini 5:1 and Fixed Brake Rack* refers to the ganged MA and brake rack that is operated at the mainline anchor (Team-based rescues).

Team-based Mid-wall Pickoffs, *Hanging Victim*
Rescuer Considerations

1



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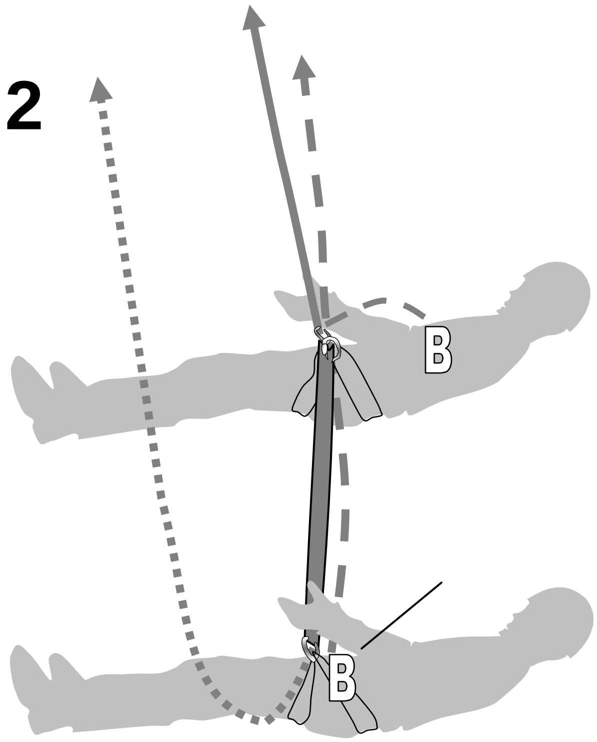


Rescuer Considerations

Step 1 – Once the rescuer has been lowered to a position even with, or slightly above the victim call for a “Stop”.

Step 2 – Make a connection between the Doubled Long Tail Bowline and the Victim using a pick-off strap or short webbing loop.

Another good option for the victim’s primary connection can be accomplished by using a short purcell which is prusiked onto the mainline just above the Doubled Long Tail Bowline. Tension this primary victim connection as much as possible before the command to haul.

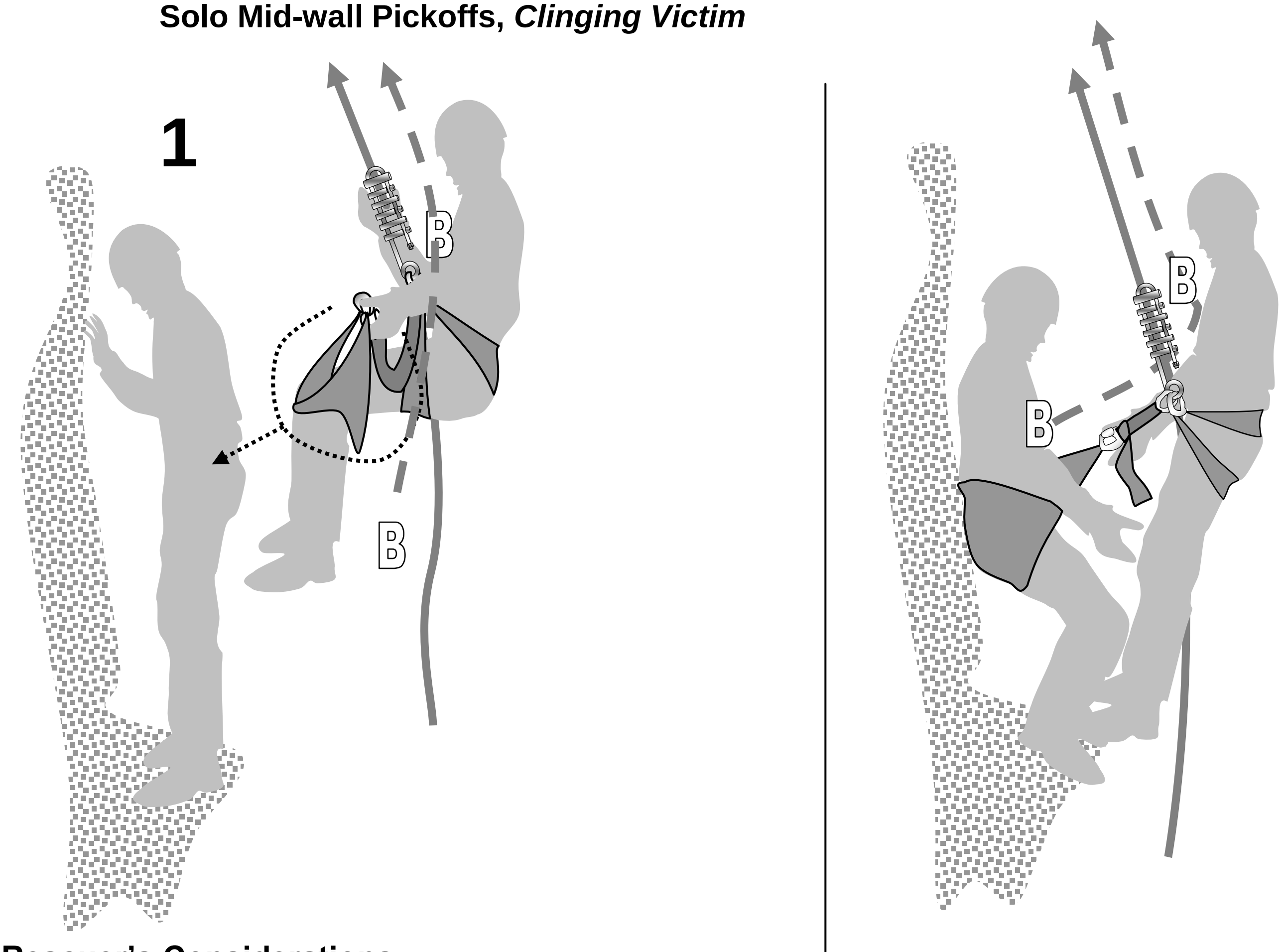
Step 3 – Tie the remaining long tail of the bowline to a second point on the victim’s harness.

Step 4 – Once these victim connections are complete call for a “Up Rope”.

Step 5 – The top team will haul the mainline now supporting rescuer and the victim by using the pre-rigged 5:1. Once the victim’s rappel line/fall arrest system becomes slack, the rescuer will call for “Stop”, and then “Down Rope”.

***Suggestion** – Attach all the victim connections and rescue adjuncts to the Mainline prior to the start of the operation. This will facilitate a faster and safer pick-off for the rescuer and victim.*

Solo Mid-wall Pickoffs, *Clinging Victim*



Rescuer's Considerations

Step 1 – Rescuer pre-rigs the victim's harness and pick-off strap.

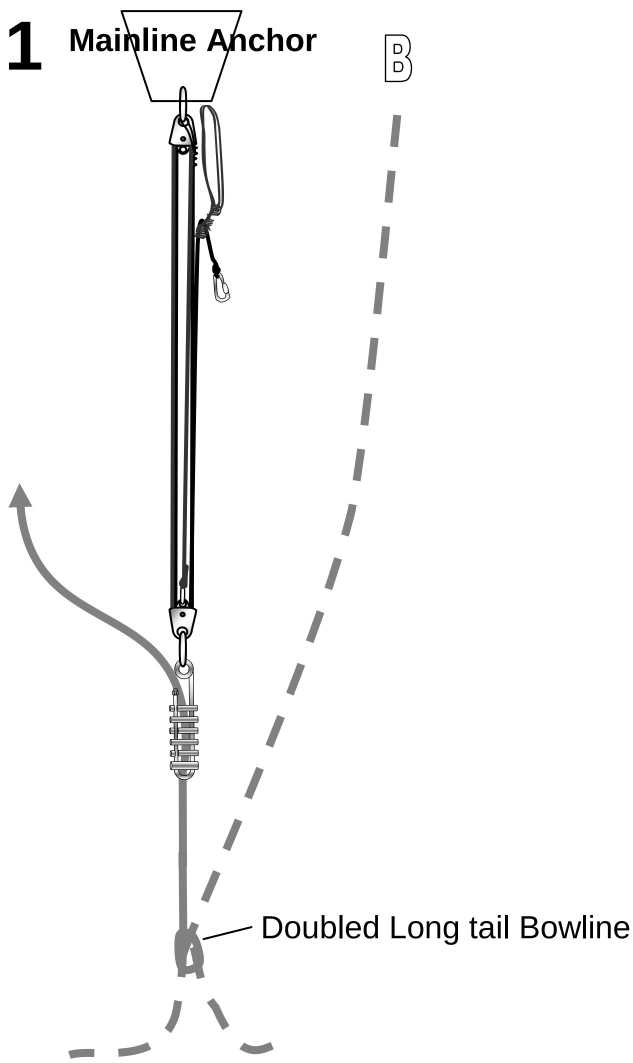
Step 2 – Rescuer stops approximately eye level to the victim, ties off the descent device, pre-rigged for maximum friction, applies the victim's harness to the victim and connects the end of the belay line to the victim, either by tying the belay rope directly to the victim's harness or clipping it onto the victim's harness via a screw-link (avoid using carabiners for the belay connection).

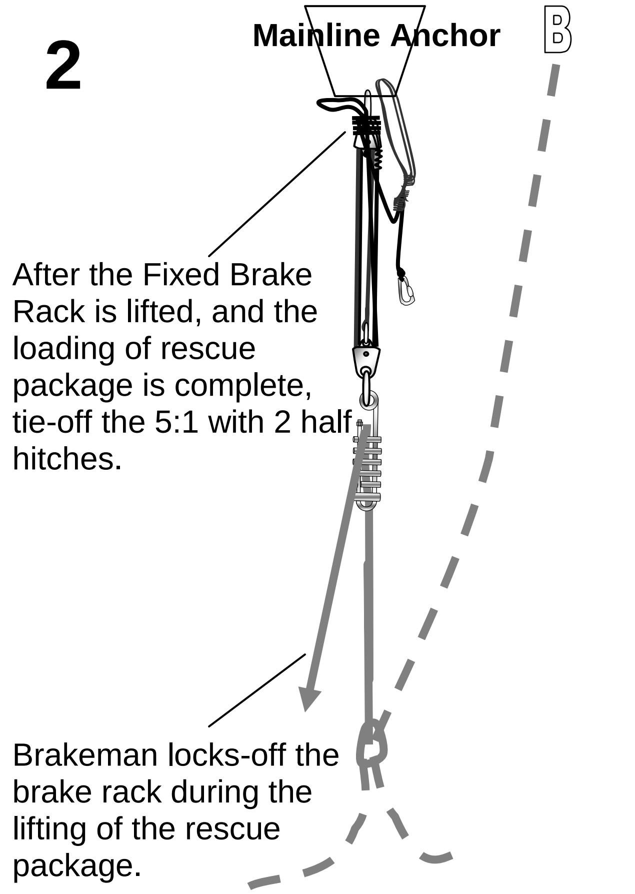
Step 3 – Once the victim's connections are made, take up as much slack as possible in the pick-off strap then tie-off the pick-off strap using an Overhand Stopper.

Step 4 – Have the victim gently weight his/her's connection by totally sitting in the victim's harness. Once the victim is completely on the rescuer's system, the rescuer may then un-tie the descent device, and rappel to safety.

Belay Line Connections
Belay line is attached to the rescuer by employing a bowline with a four foot tail to the chest "D" ring of the rescuer's class III harness. The long tail of the bowline is used to tie the end of the belay line to the victim. As stated before, the bowline is the perfect knot for the rescuer's attachment point because it facilitates the adjustment of the slack between the two parties without disconnecting it from the rescuer.

Team-based Mid-wall Pickoffs, *Clinging Victim*
Utilizes a *Fixed* Mini 5:1 and a *Fixed* Brake Rack





Mainline and Belay line Operations

Step 1 – Rig the Fixed Brake Rack to a fully extended mini 5:1 which is rigged to the mainline anchor.

Step 2 – Rig a system belay (i.e. tandem prusiks).

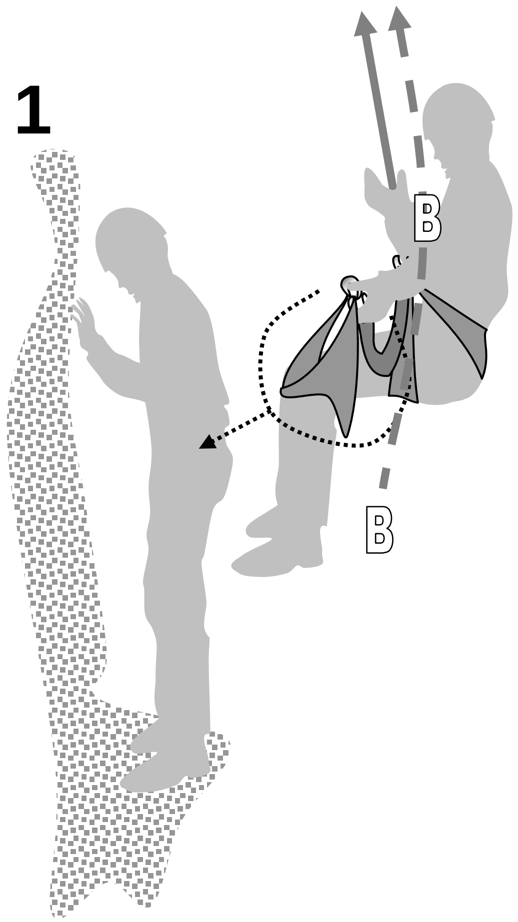
Step 3 – Rig a Doubled Long Tail Bowline to the rescue end of the Mainline and Belay line, and connect the rescuer's harness waist "D" ring to the Doubled Long Tail Bowline. Tie one of the long tails of the bowline a second point of attachment on the rescuer's harness.

Step 4 – After the rescuer has reached the victim, and the victim connections have been made, (see next page) the victim and rescuer may have to be lifted off the victim's perch by hauling the locked off Fixed Brake Rack using the fixed 5:1.

Step 5 – Once the victim and rescuer is lifted from the victim's perch, tie-off the 5:1 with two half-hitches, untie the Fixed Brake Rack, and resume the lowering with the Fixed Brake Rack.

Team-based Mid-wall Pickoffs, *Clinging Victim*
Rescuer Considerations

1



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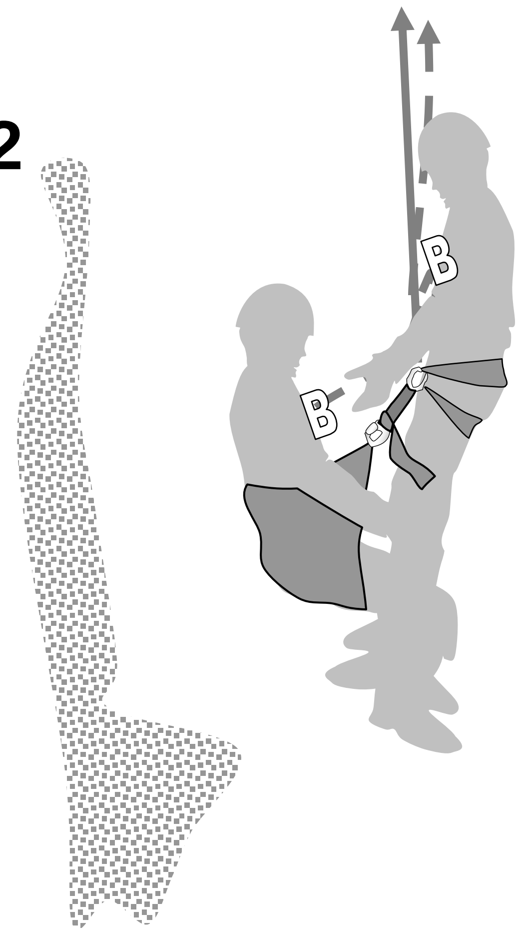

Rescuer Considerations

Step 1 – Once the rescuer has been lowered to the location of the victim, call for a “Stop”.

Step 2 – Apply the victim’s harness. Make a connection between the Doubled Long Tail Bowline and the Victim using a pick-off strap or short webbing loop.

Another good option for the victim’s primary connection can be accomplished by using a short purcell which is prusiked onto the mainline just above the Doubled Long Tail Bowline. Tension this primary victim connection as much as possible before the command to haul.

Step 3 – Tie the remaining long tail of the bowline to a second point on the victim’s harness (remember, one of the two long tails of the Double Long Tail Bowline is attached to the rescuer).

Step 4 – Once these victim connections are complete call for a “Up Rope”.

Step 5 – The top team will haul the mainline (now supporting rescuer and the victim) by using the pre-rigged 5:1. Once the victim and rescuer are lifted from the victim’s perch, the rescuer will call for “Stop”, and then “Down Rope”.

Suggestion – *Attach all the victim connections and rescue adjuncts to the Mainline prior to the start of the operation. This will facilitate a faster and safer pick-off for the rescuer and victim.*

Rescue Respone Gear Rigging Lab, Consulting and Training in Technical Rescue

Partners in Training

- **The RRG Rigging Lab works with organizations to custom build rescue training programs to meet the real life needs.**

Professional Experience

- **Highly skilled instructors with 15+ years minimum experience**

Experienced Educators

- **Certified instructors with many years of educational experience**

Equipment Knowledge

- **Complete knowledge and experience with all equipment and all major manufacturers**

Regulation Knowledge

- **Constant knowledge and upkeep of current regulations**

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