How to Determine Tree Strength and Build Tree Anchors

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Tree Anchor Strength
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The goals of a tree anchor in a rope rescue system

A tree anchor should provide a stable means of restraining a rope system having a rescue load under a specified severe loading condition. It should prevent the cordage from breaking free of the trunk. And, it should prevent significant movement of the anchor in the direction of the rescue load. Simply stated, we want our tree to stay put and hold onto our rescue system.

Is it strong enough?

Instead of relying on guidelines for selecting trees for our belay and mainline anchors based on anecdotal evidence, a better course is to base our guidelines on actual strength testing of a variety of trees. The results of such tests and conclusions drawn from them appear later in this paper.

Just how meaningful is testing; aren't there really too many variables with trees?

Yes, there are many variables – some of which are not clearly identifiable, especially on night rescues. However, with enough samples from a variety of species and soil conditions, a reasonable set of guidelines for selecting tree anchors can be established. Suggestions for these guidelines appear at the end of this paper.

Trees in Your Jurisdiction

Suffice it to say that a rescue team would be wise to become familiar with the trees commonly found it their areas – especially those in and around areas where a high incidence of accidents occur. In the Red River Gorge in Eastern Kentucky, our squad's pre-plans include identification of anchor trees at popular tourist areas.
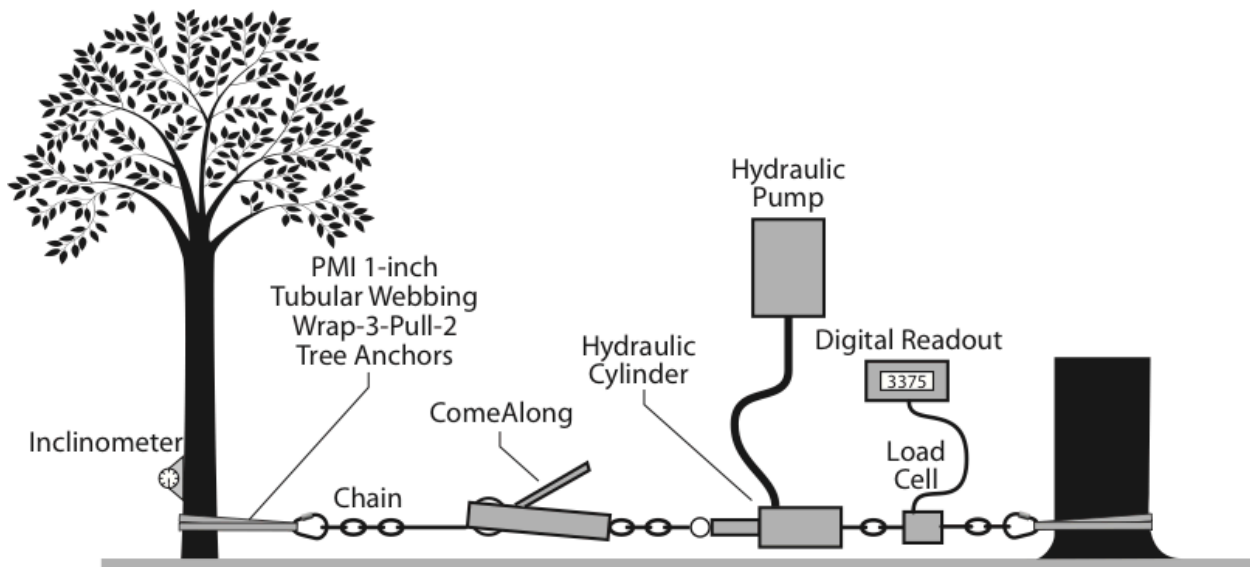

Figure 1 – Testing Rig.

The Test Methodology
Several methods were considered before arriving at the test method used for measuring strengths of trees when used to anchor rescue loads. The method chosen was as follows:
1. A test tree was chosen for testing based on its species, diameter, type of soil in which it was rooted, and location relative to other trees. All this information was recorded.
2. The diameter of each test tree was measured at a point located up the trunk from the ground at a distance equal to the diameter measured at that point. This represents a reasonable place where a rescuer would place an anchor strap or webbing, such as a wrap-3-pull-2, in building his anchor. Other testing was also done with anchors placed higher on the trunks.
3. An inclinometer was strapped to the trunk a distance up from the point that the force was applied equal to two tree diameters. Refer to Figure 1.
4. A test rig, shown in Figure 1, was then attached to the anchor strap or webbing. The other end of the test rig was attached to a larger tree that provided an immovable anchor for the test rig. This rig included, in series, these components:
    a. A webbing anchor affixed to the test tree.
    b. An NFPA G-rated carabiner connected to the webbing.
    c. A length of chain connected to the carabiner.
    d. A heavy-duty come-along connected to the chain.
    e. A means of creating a high tensile load on the system that includes:
        i. A 3-inch hydraulic cylinder.
        ii. A hydraulic hand pump is connected to the hydraulic cylinder to provide it with pressure.
    f. A means of measuring the tensile force created by the hydraulic cylinder that includes:
        i. A strain gage type load cell connected between the chain and large tree.
        ii. A signal processor with digital readout connected to the load cell for measuring and recording the force values created by the hydraulic cylinder.
    g. A large tree to serve as a master anchor for the system.
5. The system was loaded initially by the cable come-along, which was capable of applying about 6 kilo-Newtons (1350 lbf) of tension in the system.
6. Then the hydraulic pumping was started while the digital readout gage was observed.
7. The systems often had to be reset after play was removed during the first stroke of the piston in the cylinder.
8. Pumping continued until one of the following four events occurred;
    a. The digital readout reached 15 kilo-Newtons (3372 lbf). The test force was gradually increased from zero to a maximum of 15 kilo-Newtons (3372 lbf). If, at this point, the inclinometer registered less than 10 degrees of movement, the applied force was left on the rig for 5 minutes to determine if any creep would occur. If the angle remained less than 10 degrees, the test tree was considered to have passed the strength test. Why this particular value of force was chosen for these test is discussed further on in this paper.
    b. The inclinometer, affixed to the trunk, registered an angle equal to or greater than 10 degrees. If this occurred before the 15 kilo-Newtons was reached and held for 5 minutes, the test tree was considered to have failed the strength test. The selection of this particular angle is discussed later in this paper.
    c. The tree uprooted, causing the anchor system to move toward the rescue load.

d. The tree ruptured, allowing the cordage to pull entirely through the trunk. If this occurred before the 15 kilo-Newtons was reached, the test tree was considered to have failed the strength test. This particular event is discussed further on.

Justification of the Maximum Arrest Force (MAF) used for these tests
Some believe that trees should be selected for anchoring a rescue load with the thought in mind that they should be able to hold a load equal to the minimum breaking strength (MBS) of an NFPA G-rated rope. This value – 40 kilo-Newtons (8992 lbf) – is neither realistic nor prudent. If a rescue system were subjected to this magnitude of force, several more significant problems would occur long before the tree anchor became a concern.

For these tests, it was decided to use a well-recognized and widely-used MAF specified in the Belay Competency Drop Test Method (BCDTM) developed by the British Columbia Council of Technical Rescue in 1989 to specify procedures to determine belay competency in rope rescue systems. It is intended to represent the worst case scenario of a main line failure during an edge transition.
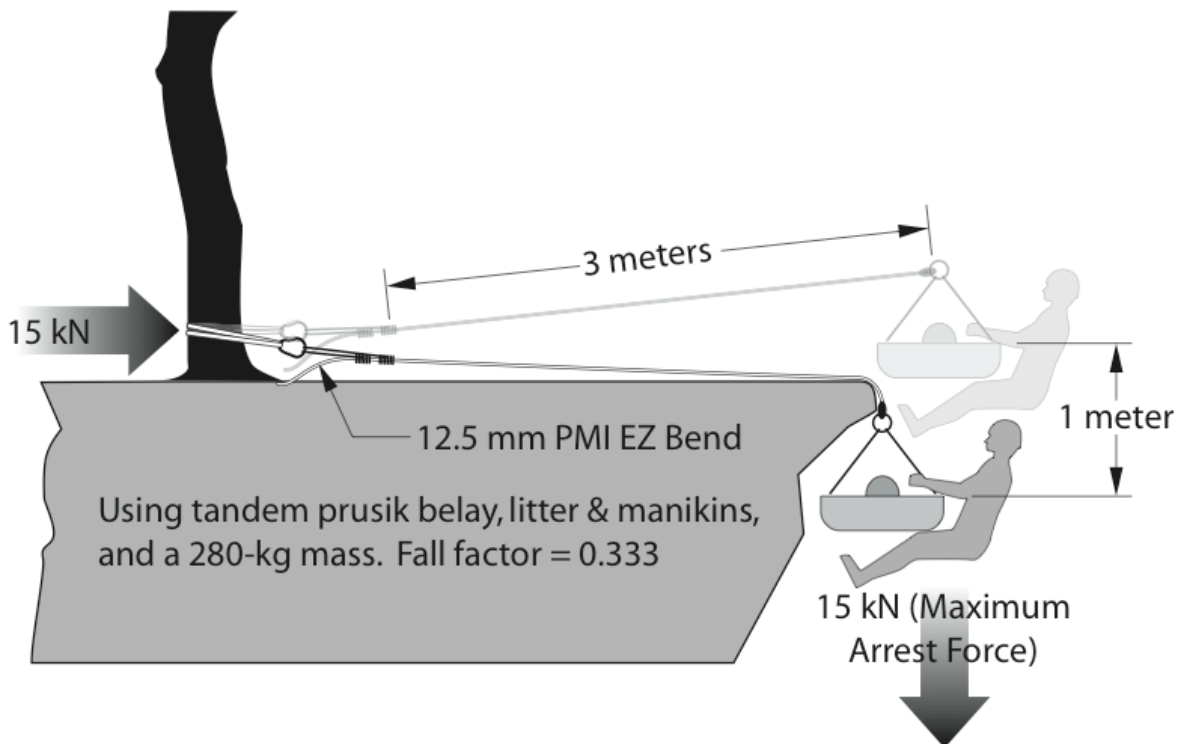

Figure 2 - Belay Competency Drop Test Method

Referring to Figure 2, in the BCDTM a 280 kg rescue load (litter, victim, patient) connected to an anchor via three meters of 12.7 mm kernmantle rescue rope is dropped one meter. With the additional travel limited to one meter, the peak force seen by the rescue load must be less than 15 kilo-Newtons (3372 lbf).

Although hypothetical situations could be envisioned in which forces greater than the one created by the BCDTM could be created, we rescuers need to work within realistic parameters and reasonable probabilities. If a tree anchor in a rope rescue system experiences a force greater that defined by the by the BCDTM there are other things of a far more serious nature going on in the system.

It can also be reasonably argued that a tree which can withstand a sustained force of 15 kiloNewtons will withstand a much higher impulse force exerted over a fraction of a second. This is due to the relatively large inertia of a tree. The energy delivered to a tree by a short impulse force of a particular magnitude is, of course, far less than the energy delivered by a force of the same magnitude sustained over a long period of time.

Therefore, the 15 kiloNewtons (3372 lbf) was chosen as the maximum force that would be applied to the test subject trees. The author is confident that this force sustained for several minutes, presents a more severe load on a tree than the BCDTM shock loading force.

It should be understood that the trees selected for testing were of sizes that were borderline capable of sustaining a 15 kilo-Newton load are not necessarily recommended sizes around which anchors should be built for rescue loads. A prudent rigger will always try to select larger trees and use ones of marginal size only when nothing else is available.

Detailed discussion of the failure modes defined for these tests:
From the previous page, we learned that there were three modes of failure:
  a. The tree trunk bent or pivoted to an angle of 10 degrees.
  b. The tree uprooted, causing the anchor system to move toward the rescue load.
  c. The tree ruptured (loss of structural integrity), allowing the cordage to pull entirely
       through the trunk.

Taking one at a time:
a. The 10-degree **change in angle** of the tree trunk was arrived at somewhat subjectively, but
     based on an unanticipated event that frequently occurred with trees less than 15 cm in
     diameter. It was discovered that when these smaller-diameter tree trunks were bent or pivoted
     by an application of force to the 1-inch tubular webbing attached thereto, at about 10 degrees,
     the webbing would shear off a large section of bark on the back of the tree and abruptly shift
     upward several inches. In some cases on some varieties of trees - conifers in particular – this
     shift was profound. The webbing – in most cases, a wrap-three-pull-two (W3P2) arrangement
     – would abruptly rupture the bark and quickly slide upward using the dislodged piece of bark
     as a sled and facilitated by the slick surface of the cambria on the inside of the bark. This
     upward movement of the cordage was accompanied by a quick increase in the angle of the
     trunk by several degrees. The change in angle was, of course, due to an abrupt increase in the
     moment applied to the tree. Although not observed in any of these tests, it is possible that this
     event could, once started, continue cascading as the webbing moved up the trunk and the tree
     bending over more and more until it either catastrophically failed or the webbing was stopped
     in its upward movement by a branch.

So it became clear that there needed to be a measurable amount of angular movement of a tree trunk, beyond which the integrity of the anchor system was considered unacceptably compromised. And, based on observations, this angle was chosen to be 10 degrees. In a pulling test, once this angle was reached, the force exerted at that point in time was recorded and the test was stopped.

It should be noted that angular movement of the trunk at the point the force is applied can be a result of either bending of the trunk (more common with flexible trees such as conifers), as shown in Figure 3, or pivoting of the entire tree, including its root ball (more common with shallow-rooted trees in unstable soil) as shown in Figure 4.
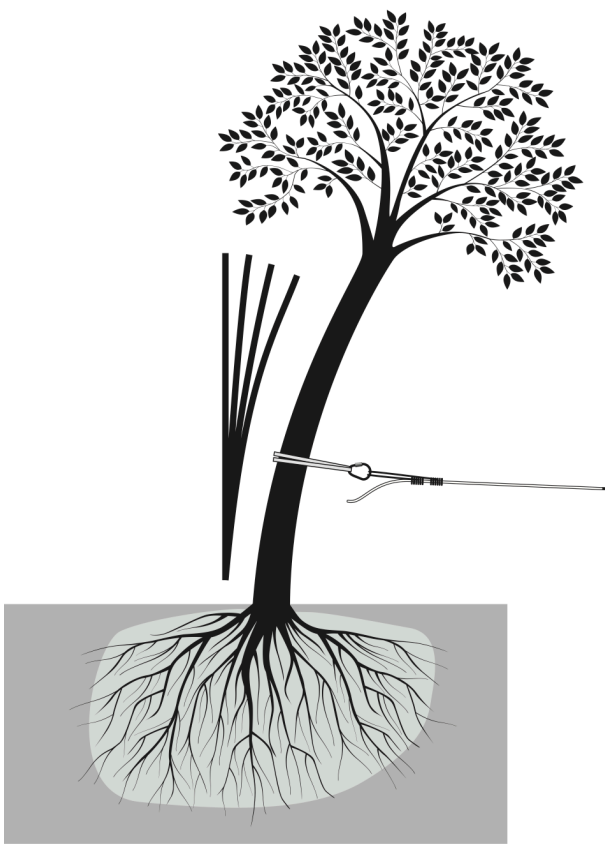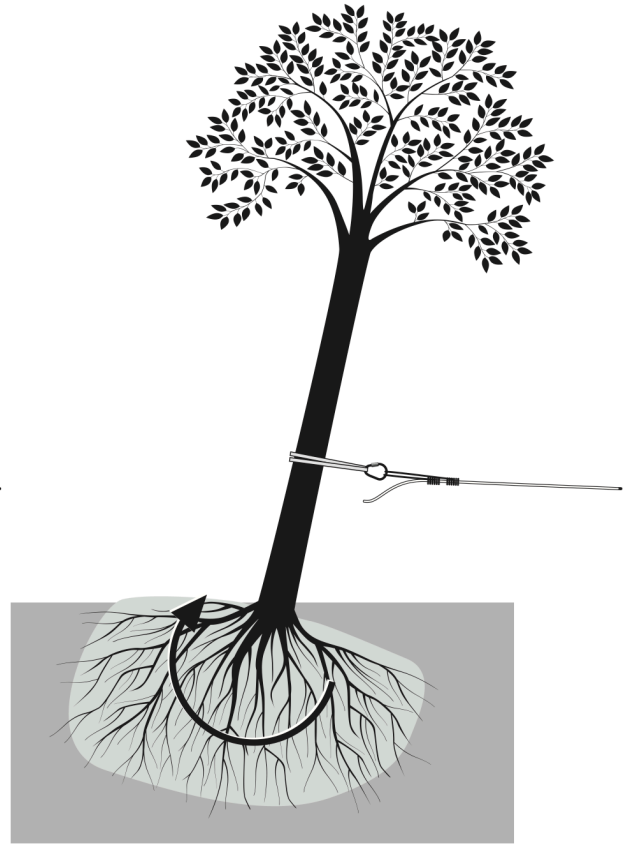

Figure 3   Figure 4 - Pivoting

b. **Uprooting** is a highly unlikely event rescue trainers love to offer up as a possible failure to justify using only large trees. Many anecdotal bone-chilling campfire stories are told to support this myth. In truth, with an anchor affixed near the base of a live tree healthily rooted in stable soil - or even shallowly rooted over the surface of a rock base - it would be a rare event to pull it over applying a force up to the BCDTM load. In these tests, smaller trees rooted in sandy soil tended to rotate – root ball and trunk – to an unacceptable angle long before they showed any signs of uprooting.

Trees of all species above 15 cm in diameter showed no signs of uprooting when the BCDTM load was applied via an anchor to the lower portion of the trunk. Of course a small tree could

be uprooted by creating a large enough moment, such as a rope pulling on a 15 cm diameter tree at a point 2 meters (6.5 feet) off the ground. But, we simply avoid affixing the anchor cordage this high without a pre-tensioned tie-back to another tree. Keeping the attachment point of the anchor low on the tree minimizes the moment to irrelevance. The load will tend to pull the entire root ball through the ground in the direction of the load long before the tree would tend to uproot.

When the anchor is very low - say 25 cm (6 inches) off the ground on a 50 cm (12-inch) diameter tree, then another factor becomes significant to the resistance of the tree to failure. At this point, as opposed to several feet up the trunk where the bending moment is the overwhelming component contributing to uprooting, the mass of the root ball and its resistance to moving horizontally contributes hugely to the resistance to failure.

c. Like uprooting, **loss of structural integrity** simply does not occur in live, solid trees above 15 cm in diameter. For example, one of the weakest North American trees, the Cottonwood (Balsam Poplar) has a compressive strength measured perpendicular to the grain of 300 psi. The cross sectional area of a 15 cm (6 inch) diameter tree is 28 square inches. Doing the math, this example will fail when a shearing force of around 8500 pounds is applied – over twice the BCDTM load. So, we will select live, non-hollow trees and not be concerned about this type of failure happening.

The following data was recorded

1. Species
2. Diameter (Measured at the point where the test force is applied. This point is located up from the ground a distance equal to one tree diameter.)
3. Soil type
4. Type of anchor (basket hitch w/webbing, W3P2 with webbing, commercial strap, etc. affixed to the tree so that the applied force is exerted at the location defined in point 2. above)
5. Proximity to other trees
6. Amount of force applied

Tests conducted

32 tests were conducted, the results of which are charted below in Figure 5. Prior to these tests, several preliminary tests were run in an attempt to determine the range of diameters for testing and to also establish techniques for efficiently conducting this type of test.
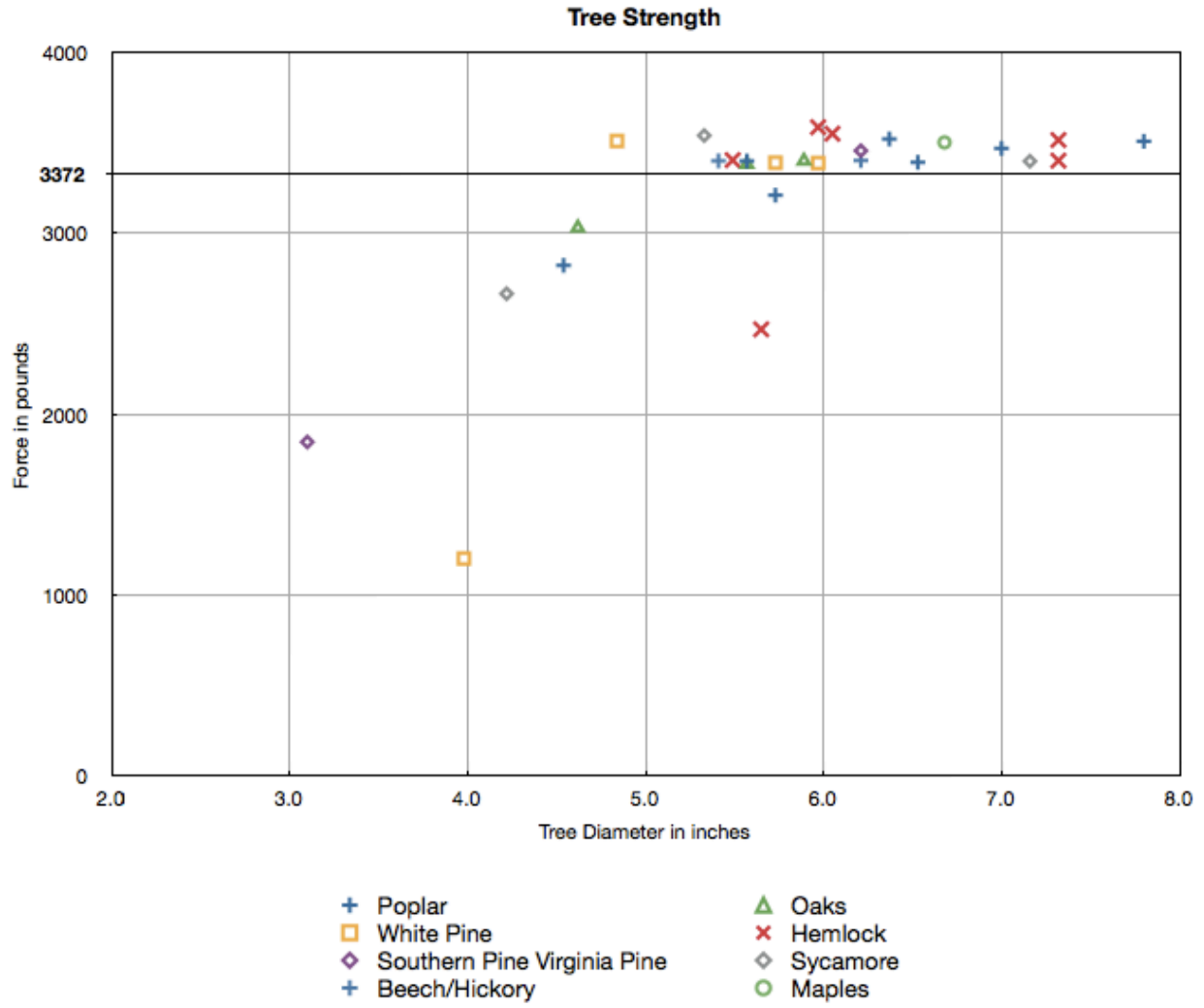
Figure 5 - Tree strength measurements.

Conclusions:

Based on the data collected and processed, suggested guideline in selecting trees to use as an anchor for a raise/lower rescue system:

If an anchor can be affixed to a tree at a point on the trunk no higher off the ground than a distance equal to the tree's diameter, then the trunk diameter at that point should be no less than 6.5 inches (16.5 centimeters). A typical rescue helmet is 8 inches wide and can provide a convenient measuring means.

Other conclusions and observations will be presented at the Symposium.

A comprehensive list of guidelines for selecting tree anchors that includes the above conclusion plus other commonly-applied guidelines:

1. In your pre-plans, get to know the species and characteristics of trees common to your area and the types of soil in which these trees are rooted.
2. Use only live trees or ones that have recently died.
3. Avoid trees with dead snags that could break off and drop onto rescuers.
4. Use the largest diameter trees available in the vicinity.
5. Don't hesitate to extend an anchor to the rigging location from a tree far back from the cliff.
6. Use front-ties when possible to raise the gear out of the ground debris and remove slack from long anchor extensions.
7. Locate webbing and strap anchors as low on the tree trunk as reasonably possible.
8. If an anchor can be affixed to a tree at a point on the trunk no higher off the ground than a distance equal to the tree's diameter, then the trunk diameter at that point should be a minimum of 6.5 inches (16.5 cm).
9. If the tree will be used as a elevator and is under 25 cm (10 inches) in diameter (measured a distance of one diameter up from the ground), a pre-tensioned tie-back should be affixed to the tree at the same height off the ground as the elevated anchor and interlaced with the webbing or straps that form that anchor. Great care must be taken to position the tie-back in reasonable line with the line of force applied by the rescue/patient package so that no sideways bending occurs.
10. Include vectoring systems of ropes to position main lines and belay ropes along their ideal lines of action.

NOTES