# Tying it all Together:

Considerations for equalizing multi-point anchor systems


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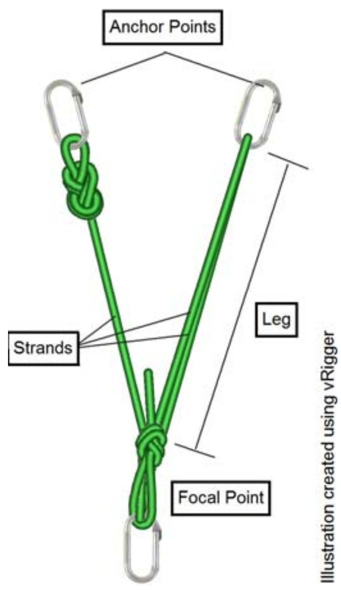
Anchoring is at the heart of technical ropework and rigging. Within the climbing and rope rescue communities, much of the anchoring involves employing the use of trees, rock mass, terrain features, vehicles, devices such as camming units, ice screws, and snow pickets. Because of the inherent uncertainty regarding the respective strengths of these various anchor points, a completed anchor system often involves multiple anchor points all configured together to produce a master point of attachment (aka focal point) for the rope and/or rigging device (see Figure 1).

Figure 1: Anchor System Overview




The differences of a completed anchor system configuration run the gamut among ropework practitioners. Some riggers use self equalizing anchor systems, others employ fixed and focused techniques. Some use figure of 8 ties and others overhands or bowlines. The specific arrangement depends upon a great many variables including direction of pull, available materials, strength of the anchor point(s), perceived need for redundancy, live versus non-live loads, personal preferences, and a whole host of other influencing factors. The perceived merits and deficiencies of each style or knot choice have been an ongoing debate for years.

Anchoring to multiple points can often be a difficult task to perform consistently well. Considerations include: available materials, quality of the anchor points, the nature of the anchoring material (ice, snow, rock, or vegetation), the technique by which to focus all of those points together, and many others. To mitigate the difficulties, various mnemonics are used to remind ourselves of the key anchoring principles; an example is the acronym "EARNEST" (equalized, angle/alignment, redundant, no extension, solid/secure, and timely). Some of the EARNEST principles are relatively easy to execute as well as inspect (i.e. redundancy, no extension, angle/alignment). However, the equalization component is largely an unknown. We don't really know how the load is distributed. We only know whether or not the anchor system held the applied force. A common reason multiple points are selected for an anchor system is that there exists an element of doubt regarding the quality of the individual anchor points. Linking those points together in a well-constructed, load sharing manner is the rigging objective – essentially, an effort to remove doubt about the overall anchor system integrity. How well is that objective being met?

In the spring of 2011, Rigging for Rescue began a test series to examine the effects of various rigging techniques in a multi-point anchoring scenario. The examinations were primarily limited to 2-point anchor systems. There were two broad questions driving the test series:

1. When we attempt to "equalize" a 2-point anchor, how well do we meet that objective?

2. If we intentionally favor a perceived stronger anchor point (i.e. distribute more force to a given anchor point), how well do our techniques match the goal?

The objectives of the test series were to:

1. Determine the distribution of forces between two anchor points given:
   a. an equal number of strands dedicated to the anchor legs
   b. an unequal number of strands dedicated to the anchor legs
   c. the presence or absence of knotted ends on a given anchor point

2. Compare whether or not the ratio of load distribution changes with a disparate amount of strands per anchor leg

3. Experiment with different 'fine tuning' techniques to determine how much effect they have on the overall load distribution

4. And lastly, a 'quick look' examination of some popular anchor-focusing techniques

The test setup included the following parameters:

1. a hydraulic ram slow pull machine was used to tension the anchor systems
2. forces were recorded using electronic dynamometers at the anchor points and at the focal point
3. the focal point tension was brought up to approximately 2-2.5 kN for each test
4. all tests involved untying and retying any knots in a given test setup and reusing the same piece of rope or cord for the subsequent test
5. all ties were dressed well and pre-tensioned by hand
6. the first slow pull results for any given test setup were discarded in order to maintain a consistent level of rope/cord relaxation conditions across multiple examinations
7. the interior angle between the anchor points was negligible (≤0-15◦)
8. leg lengths for a given test setup were equal
9. tests involved either 1m legs ("short rope in service" or Short R.I.S.) or 5.5m legs ("long rope in service" or Long R.I.S.)
10. Short R.I.S. tests used 8mm cord; Long R.I.S. tests used 11mm low stretch rope

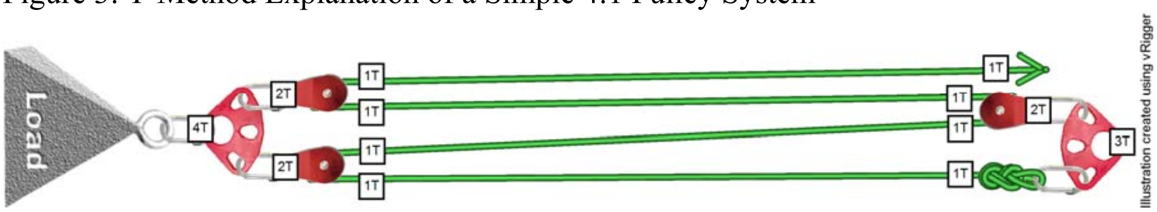
Figure 2: Test Setup Example

As a technical rope rescue educational organization, Rigging for Rescue's standard anchor-building pedagogy has been to encourage riggers to identify the stronger (or weaker) anchor points in a given anchor system and 'favor' them appropriately through thoughtful rigging. For example, if an anchor point was deemed to represent 75% of the overall strength of the anchor system, then ideally 75% of the force applied to the focal point should transfer to that anchor point. There are a variety of techniques in which to skew the overall force one direction or the other. The question really becomes, how well are we accomplishing the objective with the techniques we are employing?

To begin our research project, we conducted a series of control examinations in order to confirm/deny our presumptions about how the amount of material dedicated to a given anchor leg affects the force distribution in a multi-point anchor system. Simple pulley system principles suggest that in a 4:1 pulley system, the three strands of rope pulling against the anchor support 3/4 of the load, and the one strand we are pulling with our hands supports 1/4 of the load. This type of pulley system analysis is commonly referred to as the T-Method; the T stands for tension.

Figure 3: T-Method Explanation of a Simple 4:1 Pulley System



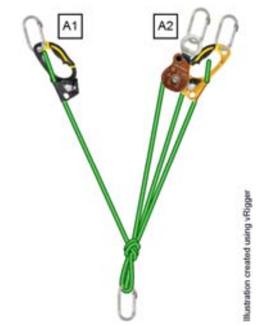
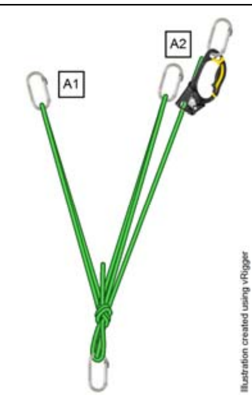

The control tests that we conducted validated that concept. In order to focus our control examinations exclusively on the amount of material (i.e. strands) dedicated to a given anchor system leg, we substituted a combination of mechanical rope grabs and pulleys in place of knots. Figure 4 illustrates the test setup for 1 strand versus 2 strands.

Figure 4: 1:2 Control Test Setup

As expected, the results indicated that Anchor Point One (A1) received 1/3 of the applied force and Anchor Point Two (A2) received 2/3 of the force. These control tests confirmed well-established pulley systems principles and also created a baseline for comparison to the user-configured test examinations.

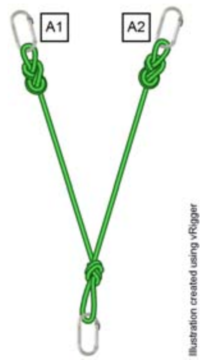
Figure 5: Summary of Control Examinations

| Description | Diagram | # of tests | Load ratio A1:A2 | | | |
|---|---|---|---|---|---|---|
| | | | min | max | mean | T-Method |
| • strands per anchor point: 1:2<br>• pulley and mechanical rope grab at focal point<br>• mechanical rope grab at anchor point 1<br>• pulley at anchor point 2<br>• 550cm per strand<br>• 11mm low stretch rope |  | 10 | 1:1.95 | 1:2.11 | 1:2.05 | 1:2 |
| • strands per anchor point: 1:2<br>• pulley and mechanical rope grab at focal point<br>• mechanical rope grab at anchor point 1<br>• pulley at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 5 | 1:1.97 | 1:2.02 | 1:1.99 | 1:2 |
| • strands per anchor point: 1:3<br>• 2 pulleys at focal point<br>• mechanical rope grab at anchor point 1<br>• pulley and mechanical rope grab at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 5 | 1:3.10 | 1:3.20 | 1:3.14 | 1:3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| • strands per anchor point: 1:3<br>• overhand knot at focal point<br>• mechanical rope grab at anchor point 1<br>• pulley and mechanical rope grab at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:2.36 | 1:4.93 | 1:3.17 | 1:3 |
| • strands per anchor point: 1:2<br>• overhand knot at focal point<br>• mechanical rope grab at anchor point 1<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:2.35 | 1:3.98 | 1:2.90 | 1:2 |
| • strands per anchor point: 2:3<br>• overhand knot at focal point<br>• mechanical rope grab at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 5 | 1:0.99 | 1:1.95 | 1:1.51 | 1:1.5 |

We began our examination of field replicable anchor system configurations by initially focusing on test setups that included an equal number of strands per anchor leg. Figure 6 summarizes statistics for both '1 strand vs. 1 strand' and '2 strands vs. 2 strands' (1:1 and 2:2) using Short R.I.S.

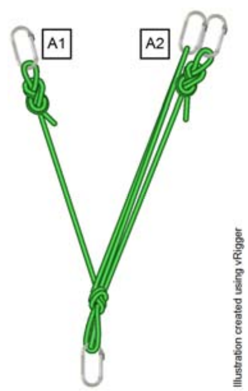
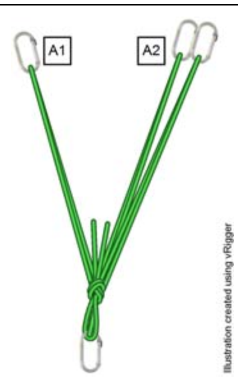
Figure 6: Summary of 1:1 and 2:2 Short Rope in Service Examinations

| Description | Diagram | # of tests | Load ratio A1:A2 | | | |
|---|---|---|---|---|---|---|
| | | | min | max | mean | T-Method |
| • strands per anchor point: 1:1<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• figure 8 at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:0.78 | 1:1.51 | 1:1.07 | 1:1 |
| • strands per anchor point: 2:2<br>• overhand knot at focal point<br>• 100cm per strand<br>• 8mm accessory cord |  | 5 | 1:1.00 | 1:1.33 | 1:1.12 | 1:1 |

T-Method force distribution principles would suggest equal tension to both anchor points given the symmetrical nature of the anchor system and equal strands per leg. The data pool supported that supposition with a mean value of 1:1.07 for 1:1 configurations and a mean value of 1:1.12 for 2:2 examinations. However, while both of these mean values were near the anticipated T-Method prediction, the ranges that encompassed the respective data sets were relatively large. This demonstrates just how difficult it can be to consistently equalize what amounts to a very basic multi-point anchor system (2-point, symmetrical, and Small R.I.S.). It also illustrates how complex and somewhat unpredictable the knot at the focal point can be from one test to the next, despite every effort to equalize the tie in a consistent and centrally-focused manner. This theme of a wide range within a data set continued to repeat itself with all of the user-configured tests involving knots (i.e. non-control tests).

Next we turned our attention to anchor systems that included a disparate number of strands per anchor point. Figure 7 summarizes data for 1:2, 1:3, 2:3, and 2:4 configurations using Short R.I.S.

Figure 7: Summary of 1:2, 1:3, 2:3, and 2:4 Short Rope in Service Examinations

| Description | Diagram | # of tests | Load ratio A1:A2 | | | |
|---|---|---|---|---|---|---|
| | | | min | max | mean | T-Method |
| • strands per anchor point: 1:2<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:2.38 | 1:4.88 | 1:3.83 | 1:2 |
| • strands per anchor point: 1:3<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• figure 8 at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:3.53 | 1:6.41 | 1:5.36 | 1:3 |
| • strands per anchor point: 2:3<br>• overhand knot at focal point<br>• figure 8 at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:0.74 | 1:1.40 | 1:0.91 | 1:1.5 |
| • strands per anchor point: 2:4<br>• overhand knot at focal point<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:1.23 | 1:3.76 | 1:2.09 | 1:2 |

The Figure 7 data sets reveal a compelling trend in examinations that included a single strand with a figure of 8 knot to an anchor point (1:2, 1:3, and 2:3). During the tests, as the figure of 8 knot tightened, material would cycle through that tie and the focal point would displace the opposite direction. The resulting overall load distribution proved to favor the side without a knot to a degree greater than what T-Method principles would predict. For example, the mean value for the 1:2 configuration was 1:3.83 whereas T-method would predict a load distribution of 1:2.00 and our own control tests resulted in a mean of 1:1.99 (Figure 5, second table). If the intention of the rigger was to favor the A2 side, then it certainly appears to be happening, but perhaps to an order of magnitude greater than presumed.

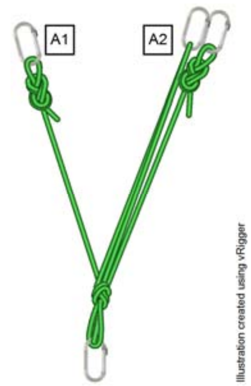
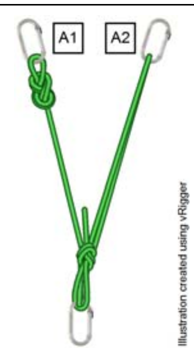
Interestingly enough, on the 2:3 tests, the mean value came out to 1:0.91. In other words, the A1 side with only two strands of material was bearing greater force than the A2 side with three strands of material. In fact, on only two tests out of ten did the A2 side record a higher force than the A1 side. During the tests of this configuration, it was visually evident that when the tension increased the knotted single strand of material on the A2 side would lengthen, and the focal point would then displace towards the A1 side.

Another interesting result occurred on the 1:3 examinations. In this test setup, both A1 and A2 had a knotted single strand terminating on their respective anchor points. Intuition would suggest that the knotted strands would more or less cancel each other out, and the mean would be close to a 1:3.00 load distribution. However, the mean came out to 1:5.36 and the minimum recorded value was 1:3.53. It is likely that the difference in tension on the two knotted strands resulted in a disparity of material cycling through those ties, influencing the focal point displacement.

A knotted end cycling material into a tensioned strand is an intuitive concept; however, the degree to which it skewed the results was unexpected. Our suspicion was that a knotted end would have less effect on the test results if the amount of rope-in-service (per strand) was increased. The results below summarize our examinations of what we are defining as "Long R.I.S." The length per strand was increased to 5.5m and the material was changed from 8mm cord to 11mm low stretch rope. The 5.5m length was selected purely based on the dimensions of the garage space in which the test apparatus resides.

We conducted tests using four different anchor system configurations. One of the test setups was a control test (see Figure 5, first table) and the other three were user-configured or tied anchor systems. The user-configured results are summarized in Figure 8.

Figure 8: Summary of user-configured Long Rope in Service Examinations

| Description | Diagram | # of tests | Load ratio A1:A2 | | | |
|---|---|---|---|---|---|---|
| | | | min | max | mean | T-Method |
| • strands per anchor point: 1:3<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• figure 8 at anchor point 2<br>• 550cm per strand<br>• 11mm low stretch rope |   | 10 | 1:1.59 | 1:6.04 | 1:3.56 | 1:3 |
| • strands per anchor point: 2:3<br>• overhand knot at focal point<br>• figure 8 at anchor point 2<br>• 550cm per strand<br>• 11mm low stretch rope |   | 10 | 1:0.59 | 1:1.49 | 1:1.11 | 1:1.5 |
| • strands per anchor point: 1:2<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• 550cm per strand<br>• 11mm low stretch rope |   | 10 | 1:0.98 | 1:3.24 | 1:2.07 | 1:2 |

All of the data sets for Long R.I.S. resulted in mean values much more in line with what T-Method would predict. For example, on the user-configured 1:2 tests, the mean value of 1:2.07 was nearly identical to the control 1:2 tests' mean value of 1:2.05 using mechanical grabs and pulleys. The results seem to indicate that at 5.5m of rope-in-service, the knotted ends become much less of an influencing factor. The specific point at which the knotted strands become irrelevant was not pursued in this research project. However, 5.5m per strand seems to have achieved that point.

Given the parameters of the test setup, the Long R.I.S. data pool suggests that T-Method is a reliable tool for predicting load distribution. For example, if an anchor system included 1 strand to one leg and 2 strands to a different leg, then the load distribution ratio would be approximately 1/3 to the first leg and 2/3 to the second leg. This distribution does not seem to be the case for Short R.I.S. The knotted leg in a 1:2 Short R.I.S. test cycles too much material into the knot relative to the strand length, and prevents T-Method from being a reliable method for predicting the load distribution.

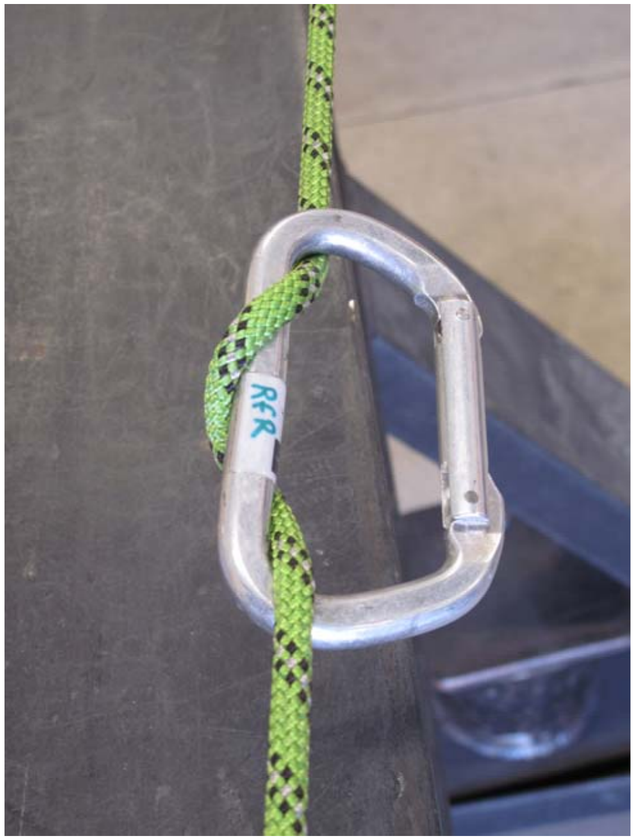
There are many available techniques for favoring an anchor point aside from dedicating more strands to that point. Examples include: skewing the focal point knot toward the anchor point to be favored – thereby shortening that leg length; shortening a given leg through the use of a round turn in the material dedicated to the carabiner attachment; the use of a Prusik hitch to make a leg length adjustable; and the use of a carabiner windlass (see Figures 9 and 10) on a strand of material. All of these techniques serve to *shorten* a given strand of material. The shortening displaces the focal point and the overall force distribution will change as a result. In an effort to better understand the subtleties of the force migration from one anchor point to the next in a multi-point anchor system, we conducted some tests using a specific 'favoring' technique. We chose to evaluate the carabiner windlass method.

The test setup for the carabiner windlass examinations included Short R.I.S. and a 1:1 material configuration. The tests involved two phases: the first phase was to tension the anchor system without the windlass and record the forces to A1 and A2; the second phase was to add the carabiner windlass to the strand of A2, re-tension the anchor system with the hydraulic ram, and record the new forces. The knotted strands going to A1 and A2 were not re-tied between phase one and phase two of the examination.

Figure 9: Carabiner Windlass Examination

| Description | Diagram | Test # | no windlass | with windlass | percent change, before and after windlass | |
|---|---|---|---|---|---|---|
| | | | ratio A1:A2 | ratio A1:A2 | A1 | A2 |
| • strands per anchor point: 1:1<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• figure 8 at anchor point 2<br>• 100cm per strand<br>• 8mm accessory cord<br>• one-wrap carabiner windlass on strand 2<br>(NOTE: diagram shows 2-wrap windlass, see Fig. 10 for 1-wrap windlass example) |   | 1 | 1:0.81 | 1:1.23 | -18.8% | 23.2% |
| | | 2 | 1:0.84 | 1:1.27 | -18.9% | 22.5% |
| | | 3 | 1:0.77 | 1:1.16 | -18.1% | 23.5% |
| | | 4 | 1:0.96 | 1:1.39 | -18.0% | 18.9% |
| | | 5 | 1:0.77 | 1:1.09 | -15.5% | 20.1% |

Figure 10: 1-Wrap Carabiner Windlass




The carabiner windlass method resulted in a smaller change in load distribution than the technique of dedicating an additional strand to an anchor point. This is a significant takeaway. If your intent is to favor a given anchor point slightly, then the carabiner windlass technique may be a viable method, offering a more subtle change in the load distribution. If your intent is to favor a given anchor point more significantly, then the additional strand technique may be the better choice producing a more pronounced change in load distribution.

The last examinations included in our research project involved tests replicating some common anchor system configurations. Two systems were evaluated: (1) a 2:2 with one strand including a flat overhand tie (aka Euro Death Knot) joining the two ends (see Figure 11) and (2) a 1:2:1 configuration. This second test setup was the only 3-point anchor system that was included in the research project (see Figure 12). Both test setups used Short R.I.S. and 8mm cord.

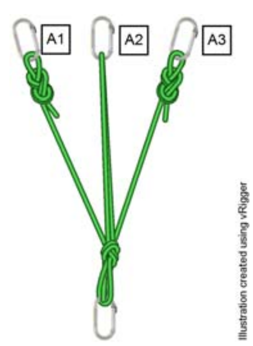
 

Figure 11: 2:2 with Flat Overhand Bend Examination

| Description | Diagram | # of tests | Load ratio A1:A2 | | | |
|---|---|---|---|---|---|---|
| | | | min | max | mean | T-Method |
| • strands per anchor point: 2:2<br>• overhand knot at focal point<br>• overhand bend on anchor leg 1<br>• 100cm per strand<br>• 8mm accessory cord |  | 10 | 1:1.81 | 1:2.28 | 1:2.01 | 1:1 |

The inclusion of a tie on one of the four strands significantly effects the load distribution of the anchor system. The mean ratio of 1:2.01 was well off from the T-Method prediction of 1:1.00. The other 2:2 Short R.I.S. tests that had no ties in the strands produced results much closer to a 1:1.00 balance (mean of 1:1.12 – Figure 6, second table). In light of the fact that both configurations can be tied with a similar length of material, there appears to be no compelling reason to use the flat overhand method, unless your intention was to favor the opposite anchor leg.

Figure 12: 1:2:1 Examination

| Description | Diagram | | Percent of force applied | | |
|---|---|---|---|---|---|
| | | | A1 | A2 | A3 |
| • strands per anchor point: 1:2:1<br>• overhand knot at focal point<br>• figure 8 at anchor point 1<br>• figure 8 at anchor point 3<br>• 100cm per strand<br>• 8mm accessory cord |  | Mean | 12.7% | 70.4% | 16.9% |
| | | Min | 7.7% | 60.1% | 12.0% |
| | | Max | 20.2% | 80.3% | 19.7% |

The final test setup of 1:2:1 produced results similar to the other tests involving tied ends in that the knotted strands on the “1” sides bore a much smaller percentage of the overall force than T-Method would predict. The only surprise was the order of magnitude by which this anchor system favors the untied 2-strand leg. The untied 2-strand leg recorded forces that were approximately five times as great as either of the two “1” sides (A1 or A3). This serves to illustrate just how much more this particular 3-point anchor system equalization method favors the 2-strand leg. The A2 anchor point with the unknotted 2-

strand piece of cord was directly in line with the focal point and direction of pull in all of the tests; that is undoubtedly a significant contributing variable to the overall load distribution.

The way in which we end up tying it all together can have a significant effect on the load distribution in a multi-point anchor system. This is particularly true with systems involving smaller amounts of rope-in-service. If a given anchoring configuration is executed by a rigger with critical evaluation and specific intent, the resulting load distribution can produce a desired effect. However, performed with a haphazard or rote methodology, the results may be such that the weakest anchor point in given system is bearing a high percentage of the overall applied force.

There are a tremendous number of variables in a multi-point anchor system: the elongation properties of the rigging material (Nylon, Dyneema, Polyester, or others); the symmetrical or asymmetrical nature of the overall anchor system; interior angles; overall rope-in-service; the type of focal point knot (overhand, figure of 8, bowline); the person tying that knot and their focusing method; and many others. This research provides a glimpse at one piece of a much larger puzzle.

However, despite the limited scope of the research, there are some key takeaways that can be garnered from the test results:

- The way in which we configure the rigging material does have a significant effect on the force distribution.
- Recognize that any user-configured tied system will have a relatively large bandwidth of force distribution relative to the mean. When we think we are "equalizing" a system, we are probably not as close to 50/50 as we assume.
- Dedicating more strands to an anchor point typically increases the percentage of force to that anchor point (all other variables held constant).
- With Short R.I.S., a knotted strand on an anchor point typically causes the force to migrate towards the opposite anchor point (all other variables being held constant).
- With Long R.I.S. and a symmetrical 2-point anchor system, T-Method pulley system principles offer a reasonably accurate estimate for force distribution.
- For anchor systems with a marked difference in anchor point strengths (e.g. large tree combined with a smaller shrub), the dedication of strands method is likely your best course of action – use T-Method as a guide for distribution percentages in Long R.I.S. scenarios.
- For anchor systems with a small difference in anchor point strengths (e.g. 15cm diameter shrub and 10cm diameter shrub), maintain equal dedication of strands and apply a 'fine-tuning' technique such as the carabiner windlass, or something similar.

At the end of the day, the anchor systems that we build and use as riggers are typically very robust and significantly over-engineered for the forces they are bearing. If that were not the case, the ITRS symposium would include an annual review of the myriad anchor system failures from the climbing and rescue communities. Generally, we are so overbuilt that we do not reveal to ourselves just how poorly equalized we may be in any given system.

Where this research has perhaps the greatest value is when you are contending with sub-optimal anchor points. Under these conditions, a well thought out anchor system that provides the intended load distribution will be the ideal approach. Making these types of finer discriminations between the qualities of anchor points is very much a judgment-based skill set that requires a lot of understanding and experience. Consider the information garnered from this research as another tool in the tool box for making better anchoring decisions by applying critical thinking.